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HAIL DAMAGE IN IOWA, 1923–1948

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ABSTRACT

A distinction is made between hail as a meteorological phenomenon and hail as an economic phenomenon. A method of collecting hail damage statistics is described, and the statistics are subjected to adjustment to a common dollar base. Since there are marked differences in the use of land and in the size of counties and crop reporting districts, the data are reduced to show the dollar damage for each 1,000 acres of cropland. The resulting data are comparable, area for area and year for year. Variations in the dollar damage are shown for the different sections of the State and for the years of record. An enveloping curve is developed which shows the maximum damage for each 1,000 acres of cropland for units of area varying in size from a single township to the State as a whole. It is noted that the adjusted dollar data on damage per 1,000 acres do not reflect meteorological factors alone, but include production factors as well. A further adjustment is made, using a crop production index developed by the Iowa Department of Agriculture. The resulting damage data, as influenced by meteorological factors alone, shows less variation between the various sections of the State.

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INTRODUCTION

Widespread interest in hail naturally falls into two fields: first, hail as a natural phenomenon; and second, hail as an economic phenomenon. The processes by which hail is formed have been examined in many meteorological papers. The distribution of hail as a climatological phenomenon has also been the subject of many papers; it will be mentioned here only briefly to show the variation in the occurrence of hail across the State of Iowa. This paper will treat hail as an economic phenomenon, and will consist principally of an analysis of hail damage data collected in Iowa for the 26-year period 1923-48.

HAIL AS A CLIMATOLOGICAL PHENOMENON

Shands [1] compiled hail data for 219 first-order Weather Bureau stations in the United States for the period 1904-43. It was shown that hail frequency in Iowa averaged between two and four occurrences annually at the points for which the data were compiled. This frequency may be compared to a frequency of four to six annually over a large portion of the central Rocky Mountains with a maximum frequency of 9.5 at Cheyenne, Wyo. The frequencies for Iowa stations are given below:

Station	Years of record	Average annual frequency	Maximum annual frequency
Charles City	39	2.4	8
Davenport	40	2.6	8
Des Moines	40	3.4	9
Dubuque	40	2.8	8
Keokuk	38	2.8	7
Omaha, Nebr	40	4.0	8
Sioux City	40	2.9	6

The above data are for "point" observations. In the case of hail, the "point" of observation is used rather loosely, and usually includes the metropolitan area for which the observer has immediate knowledge. In any case, the area covered is seldom more than a few square miles in extent. Since hailstorms cover a small area, normally about 20 square miles, the number that may be observed at a single point is relatively small. Shands has also computed the average yearly number of days with hailstorms, 57.9, that occur in the State of Iowa, an area of 56,000 square miles, for a 25-year period, 1916–40. These latter data are taken from the records of 120 cooperative observers in the State, or roughly one observer to every 500 square miles. It is very unlikely that all hailstorms were reported from so sparse a network.

Hydrometeorological Report No. 5 [1] also gives the monthly frequency of hailstorms in Iowa. The data are reproduced in figure 1. The greatest frequency is in the month of June, with an average more than 10. The adjacent months, May and July, each have nine or more hailstorms annually; the 3 months, May, June, and July, account for almost half of the annual occurrences. This period includes the planting and early stages of the corn crop, and also the early stages of the soybean crop. While hail may occur in any month of the year, 85 percent of all occurrences have been reported in the growing season, April through September.

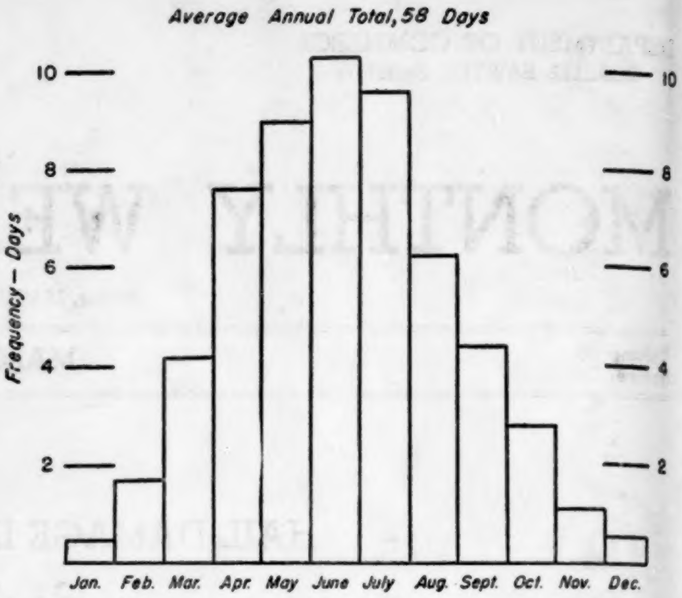

FIGURE 1.—Average monthly frequency of hail in Iowa. Based on data for the period 1916–40 (after Shands [1]).

HAIL AS AN ECONOMIC PHENOMENON

While the probability of hail striking any particular farm or any particular field of grain is small, the effects of hail upon the individual farmer or grain grower may be disastrous. As a result, the utilization of insurance to offset the possibilities of individual disaster by hail damage has become widespread in the grain growing areas of the Midwest. Flora [2] has shown that the damage by hail to the wheat crop in Kansas amounts to 4 percent of the total production in the State. Reed [3] computed the average losses in Iowa to the corn crop as 1.05 percent of the total value of the crop, with a variation from 0.50 to 2.13 percent in individual years.

COLLECTION AND ADJUSTMENT OF HAIL DATA

It has been shown that statistics on the frequency of hailstorms taken from sparse networks are not wholly inclusive. The same statement may be made in regard to statistics of hail losses. In recent years, the Crop-Hail Actuarial Association has undertaken to compile complete hail statistics [4]. Prior to this and other similar recent attempts to compile hail statistics, Reed undertook to collect hail statistics in Iowa through the facilities of the Assessors' Annual Farm Census. This census was taken late in the year, with each of the 200,000 farmers in the State asked to estimate the dollar damage caused by hail on his farm during the past season. This method of collecting hail damage statistics has certain weaknesses which have been pointed out by Reed [5] and by Decker [6]. On the other hand, the question has remained the same for the period of record, and the method of collecting and tabulating the data has been consistent. Its greatest value lies in the completeness of coverage within the State's boundaries. The question was dropped from the annual census in 1949 to make space for items of more immediate importance to the farm interests.

DISTRIBUTION OF HAIL DAMAGE

The average hail damage per 1,000 acres cropland for each county in the State is given in table 1 and figure 2. The average for the State as a whole is 143 (dollars for each 1,000 acres of cropland). The range of the county averages is 345, from a low of 17 in Lucas County to a high of 362 in Plymouth County. From the frequency distribution of hailstorms, a ratio of hail damage of 2 : 1 may have been anticipated in the State, but the actual ratio of 20 : 1 was far greater than expected.

The arithmetical average is a poor statistic. This is shown by the average for such counties as Winneshiek in the northeast and Keokuk in the southeast, where the occurrence of a few very damaging hailstorms resulted in high averages for the period of record. The median values for each county were then computed; these are shown in table 1 and figure 3. The medial value for the State is 117 (dollars for each 1,000 acres of cropland). The range of county values is 138, from a high of 139 in Ida County in the west-central section to a low of 1 in Davis and Van Buren Counties in the southeast. The ratio between the average and median appears to be least in the northwestern counties, where hailstorms of moderate severity are not uncommon (e. g., Plymouth County, average 362, median 85), and greatest in the southeastern counties where hailstorms of even moderate intensity are

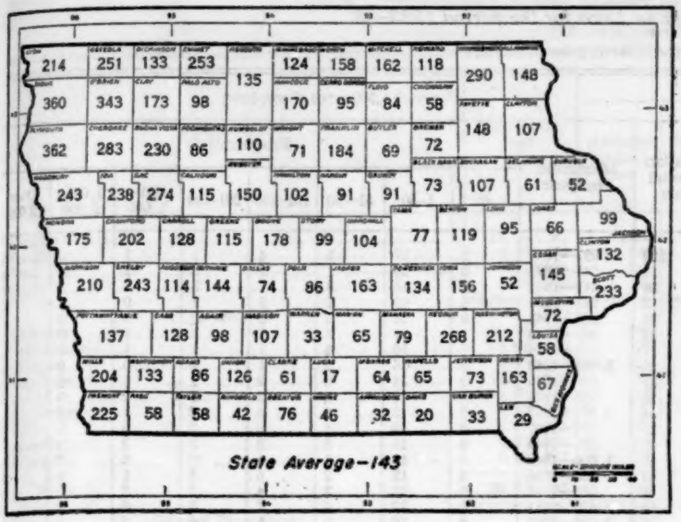

FIGURE 2.—Average annual hail damage per 1,000 acres of cropland in Iowa. Based on data for the period 1923–48 with damage adjusted to the 1909–14 price index.

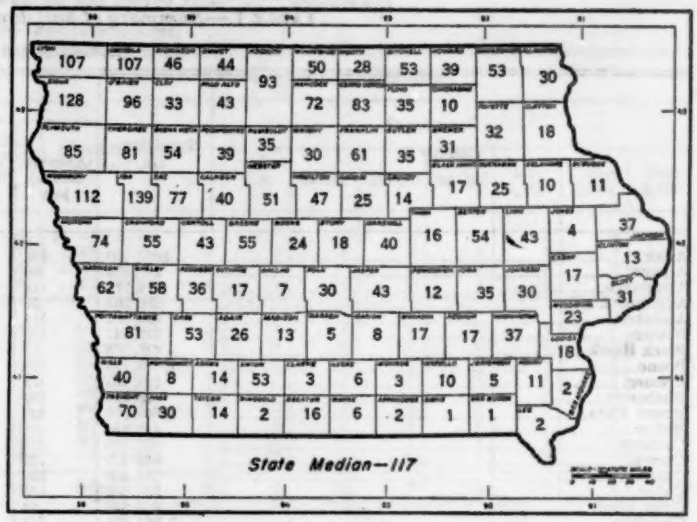

FIGURE 3.—Median annual hail damage per 1,000 acres of cropland in Iowa. Based on data for the period 1923–48 with damage adjusted to the 1909–14 price index.

relatively infrequent (e. g., Des Moines County, average 67, median 2). By reference to the median, the effect of the occasionally very severe hailstorm is minimized, as in the instances of Keokuk and Scott Counties.

Table 1 also includes data for the nine crop-reporting divisions of the State, and for selected townships in the State. The crop-reporting districts provide a convenient area intermediate in size between that of the State and the smaller county units. They also tend to group together counties having similar characteristics as to hail damage. The townships were selected to give examples of townships with excessive hail damage, those with little or no damage, and others intermediate between the two extremes.

The period during which the hail damage statistics were collected was from 1923 through 1948, a period which includes the boom years of the late twenties, the depression years of the early thirties and the war years of the early forties. Dollar values fluctuated greatly over this period, and the data for 1 year are not comparable to those of other years without adjustment. Since the major damage in Iowa is to the corn crop, it was decided to make adjustments using the annual Iowa Index of Prices Received—Grain, computed to the base period August 1909–July 1914=100. (Iowa Department of Agriculture [7]). Unless otherwise noted, all dollar data used in this study have been adjusted to that level. The process has been to convert the annual damage on the county basis to 1909–14 dollars and use the converted dollar damage in all subsequent calculations. The price indices used are as follows:

Year	*Index*	*Year*	*Index*	*Year*	*Index*
1923	122	1933	54	1943	172
1924	147	1934	104	1944	190
1925	161	1935	129	1945	185
1926	114	1936	129	1946	238
1927	136	1937	161	1947	330
1928	149	1938	75	1948	329
1929	138	1939	73		
1930	122	1940	95	(1950	235)
1931	77	1941	106		
1932	44	1942	135		

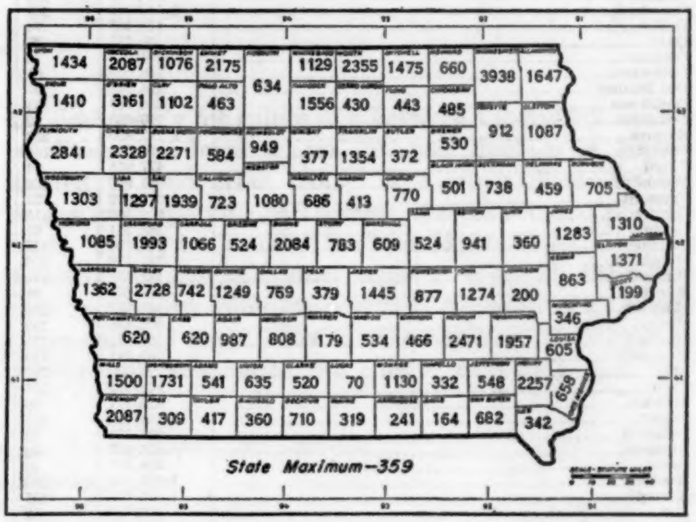

FIGURE 4.—Maximum annual hail damage per 1,000 acres of cropland in Iowa. Based on data for the period 1923–48 with damage adjusted to the 1909–14 price index.

While use of a standard price index makes it possible to compare one year with another for any given area, it is still not possible to compare one political division with another because of the wide variation in total area and in the use of that area. To meet these objections the number of 1,000-acre units of harvested cropland in each county was computed from data given by the Iowa Department of Agriculture [8]. The final data, in terms of dollar damage for each 1,000 acres of cropland and with dollars adjusted to the 1909–14 base, are directly comparable, year for year, and area for area. The data are summarized in table 1; selected statistics from the table are shown in figures 2–4.

Maximum hail damage, for each 1,000 acres of cropland, is shown in table 1 and figure 4. During the 26 years of record the maximum hail damage for individual counties varies from 70 (for each 1,000 acres of cropland) in Lucas County to 3,938 in Winneshiek County. The maximum

TABLE 1.—*Summary of hail damage in Iowa for the period 1923–48*

[Losses adjusted to the 1909—14 price index]

County	Total damage	For each 1,000 acres of cropland: Average annual loss	Median annual loss	Maximum and year	Frequency: 0	1–50	51–100	101–200	201–500	501–1,000	1,001–2,000	Over 2,000
Adair	$497,970	$98	$26	$987—1942	0	17	3	4	1	1	0	0
Adams	297,089	86	14	541—1925	0	19	1	2	3	1	0	0
Allamakee	574,171	148	30	1,647—1944	2	15	3	1	3	1	1	0
Appanoose	106,005	32	2	241—1926	4	16	2	3	1	0	0	0
Audubon	599,880	114	36	742—1943	0	14	6	2	0	4	0	0
Benton	932,247	119	54	941—1944	1	11	6	2	5	1	0	0
Black Hawk	428,768	73	17	501—1934	1	16	4	3	1	1	0	0
Boone	1,173,175	178	24	2,084—1943	0	16	2	1	6	0	0	1
Bremer	324,453	72	31	530—1944	2	14	6	2	1	1	0	0
Buchanan	623,113	107	25	738—1931	0	16	3	2	3	2	0	0
Buena Vista	1,649,806	230	54	2,271—1933	0	13	4	4	2	1	1	1
Butler	433,384	69	35	372—1927	2	13	4	5	2	0	0	0
Calhoun	851,736	115	40	723—1943	0	14	5	3	2	2	0	0
Carroll	852,479	128	43	1,066—1943	0	15	3	1	6	0	1	0
Cass	713,200	128	53	620—1936	0	13	2	5	5	1	0	0
Cedar	857,603	145	17	863—1944	3	13	2	4	2	2	0	0
Cerro Gordo	615,943	95	83	430—1931	0	10	6	7	3	0	0	0
Cherokee	1,881,471	283	81	2,328,—1943	0	10	6	1	4	4	0	1
Chickasaw	294,874	58	10	485—1933	1	16	4	4	1	0	0	0
Clarke	185,870	61	3	520—1946	7	13	2	1	2	1	0	0
Clay	1,187,753	173	33	1,102—1933	1	14	2	3	3	1	2	0
Clayton	630,317	107	18	1,087—1929	2	16	3	1	2	1	1	0
Clinton	878,453	132	13	1,371—1945	4	16	2	1	1	0	2	0
Crawford	1,546,112	202	55	1,993—1933	0	13	4	4	1	3	1	0
Dallas	471,403	74	7	769—1945	6	14	1	2	2	1	0	0
Davis	60,271	20	1	164—1931	8	15	0	3	0	0	0	0
Decatur	244,579	76	16	710—1945	5	12	3	3	2	1	0	0
Delaware	348,059	61	10	459—1944	2	17	3	1	3	0	0	0
Des Moines	216,740	67	2	658—1938	8	9	4	2	2	1	0	0
Dickinson	585,704	133	46	1,076—1943	2	12	3	4	4	0	1	0
Dubuque	260,630	52	11	705—1939	3	18	1	3	0	1	0	0
Emmet	1,217,820	253	44	2,175—1932	1	13	2	4	2	2	1	1
Fayette	1,016,065	148	32	912—1933	0	16	2	4	0	4	0	0
Floyd	477,974	84	35	443—1936	3	13	4	2	4	0	0	0
Franklin	954,902	184	61	1,354—1946	2	9	3	4	6	1	1	0
Fremont	1,071,702	225	70	2,087—1943	1	10	5	4	3	2	0	1
Greene	819,189	115	55	524—1943	0	11	5	3	5	1	0	0
Grundy	545,271	91	14	770—1927	2	16	2	4	0	2	0	0
Guthrie	791,794	144	17	1,249—1943	2	12	4	3	3	1	1	0
Hamilton	741,772	102	47	686—1932	0	14	4	3	4	1	0	0
Hancock	1,181,131	170	72	1,556—1932	0	10	6	5	3	1	1	0
Hardin	593,407	91	25	413—1927	2	15	2	2	5	0	0	0
Harrison	1,463,954	210	62	1,362—1947	0	13	2	6	1	2	2	0
Henry	603,435	163	11	2,257—1925	6	11	1	2	5	0	0	1
Howard	559,631	118	39	660—1927	0	14	4	3	3	2	0	0
Humbolt	605,541	110	35	949—1924	1	13	4	4	3	1	0	0
Ida	1,221,309	238	139	1,297—1928	2	7	3	3	7	3	1	0
Iowa	821,175	156	35	1,274—1941	3	14	1	4	1	2	1	0
Jackson	426,171	99	37	1,310—1945	2	15	3	3	2	0	1	0
Jasper	1,158,754	163	43	1,445—1943	2	11	5	2	4	1	1	0
Jefferson	257,831	73	5	548—1925	8	12	1	1	3	1	0	0
Johnson	293,627	52	30	200—1927	2	13	5	6	0	0	0	0
Jones	324,037	66	4	1,283—1933	5	17	2	1	0	0	1	0
Keokuk	1,322,260	268	17	2,471—1924	0	15	4	3	1	0	2	1
Kossuth	1,685,828	135	93	634—1946	0	9	5	7	3	2	0	0
Lee	100,061	29	2	342—1925	8	14	2	1	1	0	0	0
Linn	644,151	95	43	360—1931	0	15	1	5	5	0	0	0
Louisa	206,663	58	18	605—1938	4	14	2	5	1	0	0	0
Lucas	45,610	17	6	70—1926	5	17	4	0	0	0	0	0
Lyon	1,577,703	214	107	1,434—1943	0	9	3	8	3	1	2	0
Madison	455,311	107	13	808—1937	2	15	1	5	1	2	0	0
Mahaska	406,872	79	17	466—1943	3	13	3	4	3	0	0	0
Marion	292,529	65	8	534—1945	5	13	4	2	1	1	0	0
Marshall	649,294	104	40	609—1936	2	12	3	4	4	1	0	0
Mills	891,373	204	40	1,500—1925	3	10	3	0	8	1	1	0
Mitchell	858,071	162	53	1,475—1928	1	11	6	3	3	1	1	0
Monona	1,164,500	175	74	1,085—1925	2	8	4	5	4	2	1	0
Monroe	149,262	64	3	1,130—1926	8	12	4	1	0	0	1	0
Montgomery	568,356	133	8	1,731—1925	2	16	3	2	1	1	1	0
Muscatine	287,813	72	23	346—1941	2	15	4	1	4	0	0	0
O'Brien	2,434,040	343	96	3,161—1944	0	6	8	5	3	1	2	1
Osceola	1,298,875	251	107	2,087—1947	0	10	3	4	7	0	1	1
Page	288,939	58	30	309—1923	1	14	6	3	2	0	0	0
Palo Alto	694,913	98	43	463—1947	2	11	6	1	6	0	0	0
Plymouth	3,755,793	362	85	2,841—1932	0	8	6	3	3	3	2	1
Pocahontas	658,088	86	39	584—1933	2	13	2	7	1	1	0	0
Polk	454,780	86	30	379—1928	0	15	4	2	5	0	0	0
Pottawattamie	1,353,266	137	81	620—1947	0	12	3	2	7	2	0	0
Poweshiek	760,993	134	12	877—1923	2	16	1	0	4	3	0	0
Ringgold	157,799	42	2	360—1946	4	16	2	2	2	0	0	0
Sac	1,917,915	274	77	1,939—1933	0	7	10	3	2	1	3	0
Scott	1,036,549	233	31	1,199—1938	0	16	1	1	2	5	1	0
Shelby	1,645,593	243	58	2,728—1940	0	13	2	5	3	2	0	1
Sioux	3,503,463	360	128	1,410—1933	0	8	3	5	3	5	1	1
Story	686,172	90	18	783—1943	1	15	3	3	2	2	0	0
Tama	543,885	77	16	524—1927	3	16	1	2	3	1	0	0
Taylor	236,199	58	14	417—1927	1	16	5	2	2	0	0	0
Union	397,475	126	53	635—1938	2	11	3	6	2	2	0	0
Van Buren	93,509	33	1	682—1929	9	15	1	0	0	1	0	0
Wapello	193,932	65	10	332—1925	3	14	3	1	5	0	0	0
Warren	141,676	33	5	179—1932	2	18	2	4	0	0	0	0
Washington	1,102,368	212	37	1,957—1924	1	14	4	2	2	0	3	0
Wayne	183,820	46	6	319—1926	8	12	2	2	2	0	0	0
Webster	1,316,810	150	51	1,080—1926	0	12	4	4	4	1	1	0
Winnebago	581,837	124	50	1,129—1941	3	9	5	5	3	0	1	0

TABLE 1.—*Summary of hail damage in Iowa for the period 1923–48*—Continued

[Losses adjusted to the 1909—14 price index]

County	Total damage	For each 1,000 acres of cropland										
		Average annual loss	Median annual loss	Maximum and year	Frequency							
					0	1-50	51-100	101-200	201-500	501-1,000	1,001-2,000	Over 2,000
Winneshiek	$1,790,081	$290	$53	$3,938—1933	2	11	2	5	3	2	0	1
Woodbury	2,188,659	243	112	1,303—1930	0	9	3	6	3	3	2	0
Worth	722,865	158	28	2,355—1932	1	16	4	1	3	0	0	1
Wright	522,739	71	30	377—1923	1	14	5	3	3	0	0	0
District												
Northwest	20,445,429	242	166	813—1943	0	5	4	6	7	4	0	0
North-Central	8,640,220	122	110	432—1932	0	8	4	11	3	0	0	0
Northeast	6,850,162	115	69	641—1933	0	8	10	5	2	1	0	0
West-Central	15,063,120	187	160	571—1943	0	3	4	8	10	1	0	0
Central	9,095,716	114	94	489—1943	0	7	7	10	2	0	0	0
East-Central	6,501,826	117	74	403—1945	0	10	6	5	5	0	0	0
Southwest	5,918,094	127	97	518—1925	0	7	6	9	3	1	0	0
South-Central	2,359,936	62	49	219—1945	0	13	6	6	1	0	0	0
Southeast	4,563,942	110	42	714—1925	0	15	5	3	1	2	0	0
State	79,438,445	143	117	359—1943	0	1	10	9	6	0	0	0
Selected Townships												
Chequest, Van Buren Co.	0	0	0	0	26	0	0	0	0	0	0	0
Liberty, Keokuk Co.	280,013	798	13	16,200—1924	11	9	1	0	2	1	0	2
Garfield, Sioux Co.	124,062	276	56	3,170—1929	5	6	7	3	3	0	0	2
Preston, Plymouth Co.	370,901	792	2	15,968—1932	11	7	2	1	1	1	2	1
Washington, Polk Co.	28,080	84	0	1,351—1941	22	2	0	0	0	1	1	0
West Point, Lee Co.	1,745	8	0	209—1925	25	0	0	1	0	0	0	0

figure for the State is 359, which occurred in 1943. The maximum values represent the extreme in a State population of 26, in a district population of 234, in a county population of 2,501, and in a township population of 41,600. In figure 5, the extreme damage losses, y, have been plotted against the number of acres of cropland, x, for the respective units. The enveloping curve, $y=12.6(3.5)^{10-n}$, where $n=\log_{10}x$, has been drawn to fit the data. It should be noted that the enveloping curve is applicable only for values of n between 4.0 and 7.2 and for conditions in Iowa where the hail damage is largely limited to field grain crops. The curve illustrates the necessity of applying hail insurance on the widest possible base. It has been noted that the effects of hail may be disastrous to the individual farmer. Even on the township basis, the possible losses within a quarter of a century are excessively large. Insurance companies, through their practices of reinsurance, are able to provide a wide base

TABLE 2.—*Annual hail damage in Iowa for the nine crop-reporting districts*

[Losses adjusted to the 1909–1914 price index]

Year \ District	Northwest	North-Central	Northeast	West-Central	Central	East-Central	Southwest	South-Central	Southeast	State
1923	$86,522	$328,012	$167,319	$273,929	$344,206	$170,661	$429,967	$99,632	$1,078	$1,901,326
1924	656,648	511,170	233,117	710,021	1,002,171	360,216	254,097	31,257	938,117	4,696,814
1925	441,330	385,807	423,111	624,688	485,708	445,823	926,398	79,295	1,141,543	4,953,703
1926	433,032	151,619	128,183	282,996	561,132	28,331	135,323	210,564	123,387	2,054,567
1927	557,728	355,055	619,930	320,748	605,665	728,572	141.265	82,382	312,743	3,724,088
1928	943,172	643,460	314,509	1,259,512	501,715	155,033	129,360	192,404	65,902	4,205,067
1929	1,148,422	60,173	364,744	644,044	121,381	36,487	21,205	6,576	173,176	2,576,208
1930	165,901	112,596	117,421	636,467	60,119	81,257	65,128	35,691	33,826	1,308,406
1931	127,130	338,719	373,392	138,673	204,315	336,672	166,068	45,783	59,170	1,789,922
1932	2,088,522	1,171,425	152,886	473.683	293,535	207,719	183,726	56,060	92,908	4,720,464
1933	2,246,666	213,350	1,468,515	1,290,376	158,805	428.964	37,145	694	59,362	5,903,877
1934	1,099,098	99,206	198,796	222,679	315,024	99,790	23,637	680	23,246	2,082,156
1935	219,291	42,513	76,697	120,498	19,473	127,773	130,994	4,354	2,254	743,847
1936	620,492	426,793	57,970	334,169	418,559	66,238	256,383	10,990	55,513	2,247,116
1937	147,814	125,164	41,535	385,442	109,857	14,184	74,837	213,435	61,797	1,174,065
1938	322,668	128,940	44,681	205,502	373,789	334,183	225,819	193,181	303,484	2,132,247
1939	521,030	38,583	144,465	317,029	114,863	21,104	332,299	18,812	9,366	1,517,551
1940	136,556	20,768	176,907	1,230,581	29,197	20,428	82,784	18,628	9,789	1,725,638
1941	137,670	444,995	113,101	517,519	285,831	596,012	239,915	63,866	49,628	2,448,537
1942	879,341	179,014	180,816	646,617	205,421	258,633	528,582	95,029	126,198	3,099,651
1943	2,639,723	287,176	132,757	1,766,838	1,504,240	51,801	638,930	124,489	547,604	7,693,558
1944	1,799,397	310,772	993,352	688,805	412,315	720,617	69,361	150,832	117,839	5,263,290
1945	262,756	497,795	103,975	818,201	439,798	853,518	196,659	322,597	69,953	3,575,342
1946	409,798	1,131,962	162,314	554,365	255,736	68,683	149,952	215,860	92,397	3,041,067
1947	1,459,667	460,895	16,738	469,530	50,655	118,807	298,097	79,601	26,587	2,980,577
1948	895,055	174,258	42,931	130,118	222,206	160,320	180,163	7,235	67,075	1,879,361

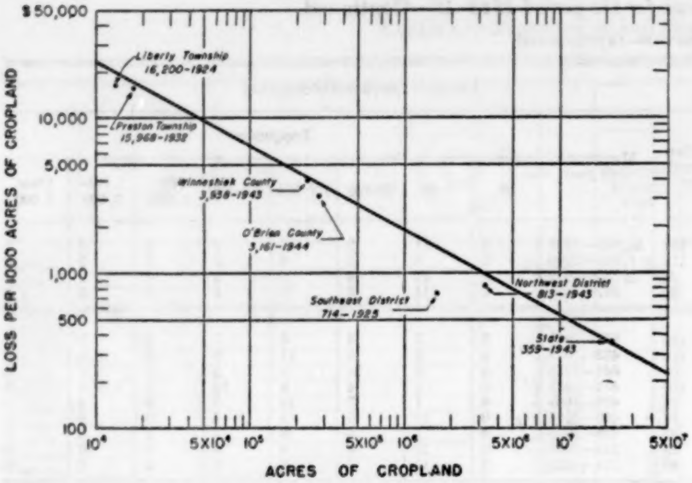

FIGURE 5.—Maximum annual hail damage, y, per 1,000 acres of cropland plotted against the number of acres of cropland, x, in the respective units (township, county, district, or State). Based on data for the period 1923–48 with damage adjusted to the 1909–14 price index. The heavy line is the enveloping curve, $y=12.6\,(3.5)^{10-n}$, where $n=\log_{10}x$.

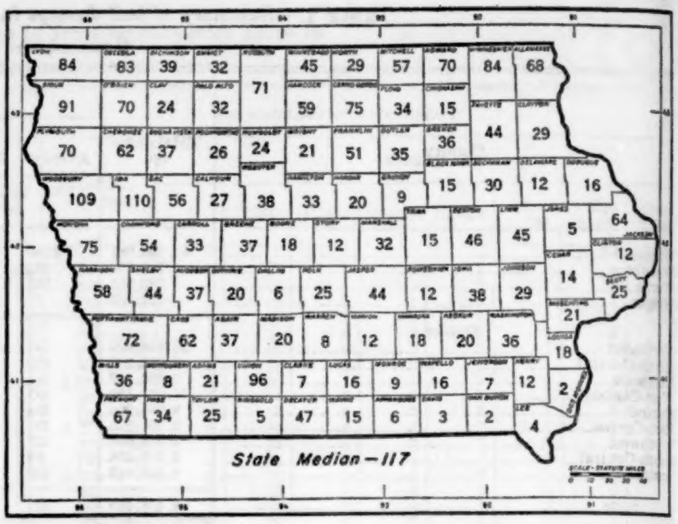

FIGURE 6.—Median annual hail damage per 1,000 acres cropland in Iowa. Based on data for the period 1923–48 with damage adjusted to the 1909–14 price index and to the 1944–48 crop production index.

for their operations, in many cases much larger than the base of the State of Iowa, which is the largest area considered in this study. It may be noted that the maximum risk for 1,000 acres of cropland in a township in Iowa is more than 45 times the maximum risk for 1,000 acres of cropland in the State of Iowa.

Table 2 shows the annual totals of hail damage for the period of record, for each of the crop-reporting districts, and for the State. The year of greatest damage in the State, 1943, had total losses more than 10 times the total losses for the year of the least damage, 1935. In terms of the 1909–14 dollar, there were 3 years in the 26-year period when the total damage for the State exceeded 5 million dollars; 7 years when it exceeded 4 million dollars; and 11 years when it exceeded 3 million dollars. If the data are desired in terms of 1950 dollars, then each loss shown in the table should be multiplied by 2.35. Some additional statistics for each crop-reporting district are given in table 3.

TABLE 3.—*Standard deviation and standard error of average annual hail damage per 1,000 acres cropland in Iowa for the period 1923–48*

District	$\bar{x}$	s	σ	$100\frac{\sigma}{\bar{x}}$
Northwest	242	222	44	18
North-Central	122	108	21	17
Northeast	115	141	28	24
West-Central	187	133	26	14
Central	114	105	21	18
East-Central	117	115	23	20
Southwest	127	116	23	18
South-Central	62	59	12	19
Southeast	110	177	35	32
State	143	80	16	11

x, annual hail damage per 1,000 acres.
$\bar{x}$, average.
s, standard deviation, $\sqrt{\frac{\Sigma(\bar{x}-x)^2}{n-1}}$.
σ, standard error $\frac{s}{\sqrt{n}}$.
$100\frac{\sigma}{\bar{x}}$, standard error expressed as a percentage of the average n, number of values of x.

ADJUSTMENT OF HAIL DATA TO LAND PRODUCTIVITY

It may be expected that hail damage would vary in the different sections of the State, in accordance with the productivity of the land. Thus, storms of similar intensity would not cause the same amount of dollar damage on land which would ordinarily produce 40 bushels of corn to the acre as compared to land which would produce 80 bushels of corn to the acre. Therefore, the adjusted hail damage, while reflecting the total damage in comparable terms, may not be wholly ascribed to meteorological causes.

The crop-production index, as given by the Iowa Department of Agriculture [9], varies from a low of 31 in Appanoose County to a high of 154 in Calhoun County (State average=100). In considering townships the range is more extreme; from a low of 19 in southern Appanoose County, to a high of 178 in southwestern Grundy County. The variation within each county is sometimes very great. Military Township in Winneshiek County, where severe hail damage occurred in 1943, has a crop production index of 92, as compared to an index of less than 50 in six other townships in that county, and a county crop production index of 63.

To ascertain the effect of the crop production index upon the hail damage data, the latter data for all counties and for the nine crop reporting districts were adjusted using the 1944–48 indices as published by the Iowa Department of Agriculture [9]. The resulting data are shown in table 4 and also in figure 6. As may have been expected, the range between the various sections of the State has been reduced. The greatest hail damage often, but not always, occurred in districts having a high crop production index. The distribution in figure 6 more closely resembles the hail frequency data. The maximum damage thus adjusted occurs in west-central Iowa in Ida County, while the minimum damage occurs in southeastern Iowa.

TABLE 4.—*Hail damage in Iowa, 1923–48*

[Adjusted to the 1909–14 price index and to the 1944–48 Crop Production Index]

District	Total damage	Average annual loss	Median annual loss	For each 1,000 acres of cropland: Maximum and year	Frequency: 0	1–50	51–100	101–200	201–500	501–1,000	1,001–2,000	Over 2,000
Northwest	$15,257,811	181	124	$607—1943	0	6	5	5	8	2	0	0
North-Central	7,448,473	106	95	372—1932	0	9	5	9	3	0	0	0
Northeast	9,383,739	158	95	878—1933	0	6	8	6	4	2	0	0
West-Central	12,765,393	159	136	484—1943	0	3	7	11	5	0	0	0
Central	7,247,517	91	75	388—1943	0	8	9	7	2	0	0	0
East-Central	6,309,423	115	73	395—1945	0	10	6	5	5	0	0	0
Southwest	6,725,085	145	110	588—1925	0	6	6	9	4	1	0	0
South-Central	5,053,401	132	104	465—1945	0	9	4	6	7	0	0	0
Southeast	6,005,187	145	55	939—1925	0	11	7	3	3	2	0	0

NOTES ON INDIVIDUAL HAILSTORMS IN IOWA

These notes have been selected, mainly from the Iowa climatological data and the Iowa weather reports, to show the conditions which attend some of the more severe hailstorms in Iowa. They are direct quotations from the original publications, and reflect the various styles and interests of the writers. References to dollar damage have been omitted, since the notes cover a period of more than 80 years with violent fluctuations in the value of the dollar.

June 30, 1863. " . . . After destroying all glass on the west side of the buildings, the wind veered around to the east, destroying also all glass on the north and east sides of most buildings in Monticello. The marks of the falling hail on the fences, buildings and trees were plainly visible for several years afterwards . . . all crops and shrubbery was battered off close to the ground . . . Upwards 500 lights of glass were smashed, and most of the families had to wait until Mr. Hickok sent to Dubuque for a new stock of glass . . ." M. M. Moulton, Monticello, Iowa.

May 17, 1877. "It commenced to hail at this station (Hamlin, Audubon County) in Hamilton township about 5 P. M. The wind had increased to nearly a storm; clouds very low and dark; hailstones measuring six inches in circumference, and falling to the ground in great force, smashing window panes, barking the apple trees, killing rabbits, birds, chickens, etc." D. C. Lewis.

June 25, 1877. "The hailstones were large—from the size of black walnuts down. They fell in vast quantities and with great force. In one place, where there was a ravine with steep slopes on each side, they were washed down into the ravine, filling it to a depth of five feet, and they were so well preserved by the rubbish washed on to them, that some were seen a week from the time they fell, although some of the hottest days of summer intervened." C. E. Tebbetts, Muscatine, Iowa.

April 21, 1878 (Easter Sunday). "Hailstones very large, measuring from five to ten inches around; some I saw measured were twelve and one thirteen inches around and four inches in diameter." Sac City.

"Immense hailstones fell in the track of the tornado, and at some distance on either side; some of these hailstones measured fourteen inches in circumference." Grant City.

"Hailstones, the size of a walnut, fell in sufficient quantity and force to break nearly all the glass on the western side of houses." Smithland.

"Very severe hailstorm, accompanied by rain, thunder and lightning; 6:30 to 7 p. m. Hailstones two and one-fourth to three inches in diameter fell . . . Most of the stones were in the shape of flat discs; some were elongated spheres, and others nearly round . . . Hail drifted two feet deep in one place." Nashua.

" . . . Where hail stripped the trees as bare as in winter, utterly ruining all fruit and breaking thousands of panes of glass . . ." Cambridge *Chronicle*.

August 6, 1890. " . . . a very disastrous storm passed over the central part of Adair County and on south into Union County . . . Mr. R. S. Williams says in a letter to me: 'The hail destroyed all green vegetation and small animals, such as rabbits, ground squirrels, etc., and all the birds. It fell to a depth of four inches, varying in size from a quail's egg to a hen's egg, and drifting in many places to a depth of six feet, where it remained, when protected by trash, for twenty-six days after the storm, or until September 1st.' The writer was past Mr. Williams' farm seven days after the storm, and took from a pile of several wagon loads, enough hailstones to freeze a gallon of ice cream. It is hard to realize what desolation this storm left in its track. In one field of corn of forty acres, there was not a sound ear to be found." Henry C. Wallace, Orient, Iowa.

"Hail commenced to fall at 7 o'clock in the evening of August 6th and continued for forty minutes . . . On the bottomlands hail was drifted from four to six feet deep, and where protected by long grass, was found in large quantities twelve days after the date of the storm. The corn crop was almost entirely destroyed . . . No livestock was killed, except a few pigs." Hugh McCornack, Creston, Iowa.

September 1, 1897. "Imagine, if you can, a tract of country at least sixty miles long and averaging two or three miles wide in which scarcely a stalk of corn is left standing . . . Imagine, if you can, a strip three to four miles wide on each side of this first strip in which on the average, half the corn crop has been destroyed; put on top of this the wreckage of hundreds of windmills, the destruction of all the glass in the north windows of hundreds of houses, the loss of thousands of chickens and turkeys, the wreckage of orchards, vineyards and gardens, the damage to barns, sheds, cribs, etc., . . . At least 40,000 acres of corn have been totally destroyed, while 70,000 acres have been so pounded and wrecked by hail that half or more of the crop is a total loss. . . At the Foster Farm . . . the stubs of the stalks stand, on an average, about two or two and one-half feet high, but the balance of the stalks, ears, blades, etc., have been pounded off and are rotting on the ground.

"At W. R. Jeffrey's farm, in Highland township, the storm . . . wrecked his fine new barn . . . Howard Jeffrey . . . was struck in the forehead with a hailstone and knocked senseless . . . the north wall . . . was blown in bodily . . . This wall was two feet thick, seven and one-half feet high, fifty-two feet long, and only three or four feet of it above ground." Washington County local paper.

March 24, 1901. " . . . hailstones containing a large percent of mineral. Many persons in Sac City noted the peculiar softness of the large stones as they fell and some who attempted to taste them found them alkaline . . . contained carbon, sodium, boron, and a little calcium . . . Mr. A. L. Bownell, voluntary observer at Sac

City writes . . . 'The hail was soft like snow, composed of pellets about the size of peas pressed together without breaking their shape . . . One (chunk) that I saw weighed fifty-seven ounces . . .' " Sac City *Sun*

June 20, 1908. "A strip of country about fifteen miles wide, extending from Cresco, Howard County to McGregor, Clayton County suffered greatly from damage to crops, by wind, rain and hail. Cattle and hogs were killed by the hail or driven by the storm into the creeks and drowned . . . At a few places in the track of the storm the hail was of such size, and was driven with such force by the wind as to break siding on residences." H.A.F.

August 1922. "The first storm occurred on the 1st and affected portions of Dubuque, Jackson, Delaware, Linn and Jones Counties . . . Dubuque reported one of the most severe storms ever experienced but the greatest destruction to crops occurred in an irregular strip from one-half to four miles wide and forty miles long from the northwest corner of Delaware County southeastward. Hail drifted to a depth of six inches. . . . The most severe hailstorm occurred on the 9th and covered a large area in the west-central portion, but the greatest damage occurred in Crawford, Shelby, Audubon and Guthrie Counties. The principal damage was to corn but chickens and young pigs were reported killed by the score and two cows were killed . . . in portions of the area whole sections were hailed out so completely that not a single whole stalk of corn was left standing. In Guthrie County fields were white with hail and ditches two feet deep were completely filled. Four days after the storm there was sufficient hail in the ditches to make ice cream." F.L.D.

July 1924. "Hailstorms were very destructive, and the principal ones were embraced in a strip from Plymouth, Lyon, and Emmet counties southeastward to Delaware, Linn and Johnson counties . . . the heaviest damage occurred in Humboldt, Franklin, Hardin, Grundy, and Blackhawk counties. Reports were received from several counties of as many as three whole sections having crops completely ruined by hail and some stones were of enormous size. In Grundy County the hail drifted from a foot to 18 inches deep, and remained on the ground for 48 hours after the storm . . . Hundreds of chickens were killed, hogs and cattle were bruised and bleeding, and many roofs were punctured by hail." F.L.D.

August 1925. "What is believed to have been the worst hailstorm in the history of the State occurred on the 18th. The storm apparently developed in the southeast corner of Poweshiek County and moved southeastward over portions of Iowa, Keokuk, Washington, Jefferson, Henry, Des Moines and Lee counties . . . Some of the stones were reported of unbelievable size, some disc-shaped were four inches across and two inches thick. Many shingle roofs were pierced and stock of various kinds were killed. Passenger trains caught in the storm did not have a whole window glass left, and all windows on the exposed side of homes were broken. Fields of corn up to 75 acres did not have a single stalk standing. The damage to crops was so complete that many tenant farmers abandoned their leases and sought other employment." F. L. D.

September 21, 1931. "A severe hailstorm accompanied the tornado . . . in Bloomfield. The large hailstones, some more than 2½ inches in diameter, driven by the wind, broke more than 15,000 glass windowpanes. Nearly every roof along the path needed repair, and at least 600 homes must be reroofed. The hail damage was confined mostly to trees, windows, roofs, highlines and telephone wires."

July 6, 1932 (3d of a series of damaging hailstorms on this date). "In Iowa the storm was most destructive in and near LeMars . . . Nearly every building in LeMars suffered damage to windows and roofs, and the tops of several hundred automobiles were riddled. A number of pigs and livestock, hundreds of chickens, ducks and geese, and literally thousands of pheasants and other wild birds were killed."

July 31, 1943, near Boone, Iowa. "In the city of Boone there was considerable damage to electric signs, windows and roofs. Two greenhouses lost 2,300 panes of glass. Some automobile tops and some roofs were damaged in the southeast part of town. Crops were badly damaged or totally destroyed on about 200 farms, or on about 8,000 acres of land. Previous to the storm there were prospects of bumper yields of corn, soybeans and hemp, but after the hail some fields contained only short stumps of broken cornstalks. . . ." S. E. D.

ACKNOWLEDGMENTS

The collection of hail damage statistics through the facilities of the Annual Farm Census originated with the late Charles D. Reed; many of the original data used in this report were compiled by Mr. Reed in a very convenient form. The reduction of the data to a standard price index was accomplished by Mr. Wayne L. Decker, and many of the same data were used by him in his study on hail frequencies. Assistance in statistical interpretations was given by Mr. M. D. Magnuson, and assistance in typing and the preparation of tables, charts, and figures by Miss Patricia Richtsmeier and Mrs. M. C. Blaess.

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CORRESPONDENCE

REMARKS ON "A PRESEASON HURRICANE OF SUBTROPICAL ORIGIN"

CONRAD P. MOOK

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February 8, 1952

I have just read the article by Moore and Davis (*Monthly Weather Review*, vol. 79, No. 10, 1951, pp. 189–195) on the May 1951 hurricane and believe that they are correct about the importance of the sea surface temperature in influencing the movement of this storm.

At the time of the May storm we were looking at the sea-surface isotherms as published by Fuglister (*Papers in Physical Oceanography and Meteorology*, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, vol. X, No. 2, 1947, 25 pp.). Here the comparison of the track with the isotherms is even more striking than that shown in Moore and Davis' figure 1. Looking at Fuglister's chart for May, one can see the cold sea surface over which the storm would have to pass if it were going to hit Long Island. The 1938 and 1944 New England hurricanes did finally move over colder water (but not as cold as in the May case) with great intensity, but they were no longer true tropical storms, apparently maintaining their energy in a manner similar to extra-tropical storms.

WILLIAM MALKIN

WBAN Analysis Center, U. S. Weather Bureau, Washington, D. C.
March 26, 1952

A comparison between an unpublished study by us on the favorable circumstances leading to the early formation of Hurricane Able, 1951, and the study by Moore and Davis (*Monthly Weather Review*, vol. 79, No. 10, 1951, pp. 189–195) brings to light: (1) a possible error in their figure 1, and (2) a variation in the solar constant associated with the hurricane occurrence.

The point concerning their figure 1 is raised by comparing it to a map in our study showing average sea-surface temperatures in May (for 5-degree latitude-longitude areas taken from *Atlas of Climatic Charts of the Oceans*, U. S. Weather Bureau, 1938). Our temperatures values are at variance with their isotherms, suggesting a possible error unless they have more complete and later data than we have. Also, a further check reveals that their 70° isotherm does not agree with the May Atlantic Ocean sea-surface temperature chart, U. S. Hydrographic Office, 1943. [Mook, in his comments has, of course, pointed to the more recent sea-surface temperature charts by Fuglister.]

Mention of our second point seems desirable for the sake of completeness of the discussion of Hurricane Able. According to Abbot (*Smithsonian Miscellaneous Collections*, Smithsonian Institution, Washington, vol. 110, No. 1, 1948), "We are not to infer that a depression of the solar constant is always necessary to bring on a hurricane. Nevertheless, frequently it appears to be the impulse which starts the cataclysm." Table 1 shows that the lowest, provisional values of the solar constant in May 1951 were recorded on the 14th and 16th. As Hurricane Able was first recognized on the 17th this is another case of a hurricane that was definitely preceded by a depression of the solar constant, as judged from the 26 recorded observations. It is of further interest to note, in table 2, that among the monthly means for the past 8 years, that of May 1951 is significantly the lowest.

TABLE 1.—*Provisional solar constant values from Montezuma, Chile (Courtesy L. B. Aldrich, director, Astrophysical Observatory, Smithsonian Institution)*

1951			*1951*			*1951*		
May	1	1.914	May	12	30	May	21	35
	2	25		13	21		22	34
	3	34		14	13		23	30
	4	43		15	15		25	26
	6	34		16	13		26	27
	7	36		17	15		29	28
	8	22		18	25		30	24
	10	28		19	29		31	32
	11	33		20	40			

TABLE 2.—*Monthly mean solar constant values, 1944–51 (May 1951 value is provisional)*

May 1944	1.944	21 values.
May 1945	47	28 values.
May 1946	47	19 values.
May 1947	43	16 values.
May 1948	50	16 values.
May 1949	44	13 values.
May 1950	44	21 values.
May 1951	27	26 values.

REPLY

PAUL L. MOORE AND WALTER R. DAVIS

U. S. Weather Bureau, Miami 32, Fla.
April 21, 1952

We thank Messrs. Mook and Malkin for their comments about our *Monthly Weather Review* article, "A Preseason Hurricane of Subtropical Origin." We are pleased at the interest shown in it.

The source of the sea-surface temperature data was an article by Giles Slocum, "The Normal Temperature Distribution of the Surface Water of the Western North

Atlantic Ocean," *Monthly Weather Review*, vol. 66, No. 2, pp. 39–43. We regret that a credit line was inadvertently omitted from the chart and the references.

While the Atlas referred to by Malkin and the article by Slocum are from the same observational material, the former gives the values for only 5-degree squares. The isotherms in Mr. Slocum's article, which we have used except for minor smoothing due to drafting limitations, are based on 1° intervals. The apparent discrepancy may result from the more exact delineation of the isotherms with the smaller intervals. The point which we were emphasizing is further supported by the fact pointed out by Mook that, based on the later publication by Fuglister, the relation between the path of the storm and the isotherm pattern is even more striking than in our original chart.

The comments by Malkin regarding the possible effect of variations in the solar constant are interesting. They suggest the desirability of examining the possible correlation with other such abnormal storms. The one along the East Coast February 2–4, 1952, is a case in point.

THE WEATHER AND CIRCULATION OF MARCH 1952[1]

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The circulation patterns of March 1952 were characterized by extreme deviations from the normal at both sea level and 700 mb. The Pacific High was abnormally strong, with positive anomalies at 40° N., 150° W. of 420 feet at 700 mb. (fig. 1) and 11 mb. at sea level (Chart XI, inset), and the anticyclone was displaced northwest of its normal position. The westerlies in the northeastern Pacific were much stronger than normal, as indicated by the line of equal height departure from normal in figure 1.

[1] See Charts I-XV following p. 58 for analyzed climatological data for the month.

This strong current underwent considerable diffluence or spreading as it crossed the mountains of western North America. The major portion veered southeastward across the abnormally deep trough with large horizontal tilt in western and central United States.

It has long been recognized that the position and intensity of the eastern Pacific High has a profound effect upon the weather and circulation of North America. To illustrate this, figure 2 has been reproduced. This figure represents an average of ten 700-mb. 5-day mean charts

FIGURE 1.—Mean 700-mb. chart for the 30-day period March 1–30, 1952. Contours at 200-ft. intervals are shown by solid lines, intermediate contours by lines with long dashes, and 700-mb. height departure from normal at 100-ft. intervals by lines with short dashes with the zero isopleths heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines.

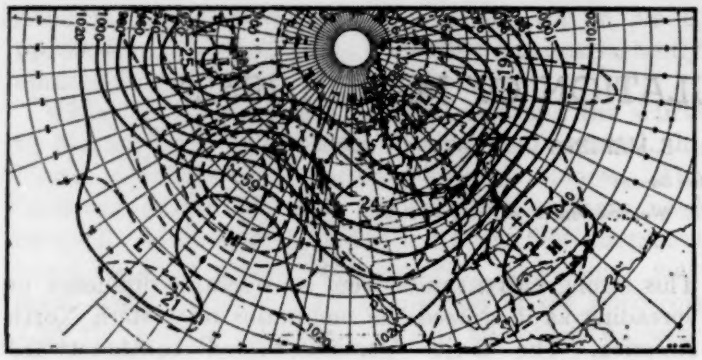

FIGURE 2.—Mean 700-mb. chart for the 10 cases of 5-day mean maps with the largest positive height anomaly at 40° N. and 150° or 160° W. during the past 6 winters. Contours at 200-ft. intervals are shown by solid lines and 700-mb. height departures from normal at 100-ft. intervals by dashed lines. Anomaly centers and contours are labeled in tens of feet.

taken from six past winter seasons, each chart of which had very large positive height anomalies at 40° N. and either 150° or 160° W. It is hoped that such a chart gives an indication of the interrelationship between the circulation of the eastern Pacific area and that of other areas of the Northern Hemisphere. Notable features of figure 2 are the deep trough and below-normal heights in western United States, the well-marked ridge and above-normal heights in eastern United States, and the low center and below-normal heights in northeastern Canada. These simultaneous interrelationships are not confined to the extreme cases selected for figure 2. For example, there was a correlation of +0.57 between the anomalies of 700-mb. height at 40° N., 150° W. in the eastern Pacific and 35° N., 75° W. near Cape Hatteras for all winter months from 1945 to 1950 [1]. This tendency for symmetry or a uniform wave structure in the atmosphere may provide the mechanism for the northward transport of momentum and vorticity throughout eastern North America to compensate for that which is transported southward in the West around the Pacific anticyclone.

The mean 700-mb. circulation observed during March 1952 closely resembled the idealized pattern shown in figure 2 in most of the eastern Pacific and western North America. On the other hand, this month's circulation pattern departed drastically from the average pattern of figure 2 throughout eastern North America and the Atlantic. Positive anomalies of 400 ft. at 700 mb. and 14 mb. at sea level were observed at 65° N., 65° W. in northeast Canada where a deep Low appears in figure 2. This is one of the largest anomalies recorded in the last 20 years on a monthly mean chart in this area. These positive anomalies extended eastward throughout the northern portions of the Atlantic resulting in a southward displacement of the Icelandic Low, as indicated by large negative anomalies in the central Atlantic (350 ft. at 700 mb. and 12 mb. at sea level at 45° N., 30° W.). Negative anomalies also extended into the eastern United States where figure 1 shows a positive anomaly center. Thus a blocking or low index type of circulation, with the principal band of westerlies displaced abnormally far south, existed throughout eastern North America, the north Atlantic, and eastward for thousands of miles across Eurasia. It is believed that this blocking condition was instrumental in preventing the occurrence of large positive anomalies in southeastern United States in harmony with those observed in the eastern Pacific.

The cyclone tracks observed during the month (Chart X) reflect the steering influence of the large scale circulation pattern. Storms were virtually absent in the regions of large positive anomaly and concentrated in the regions of negative anomaly. Migratory daily storms which moved northeastward across the Pacific were steered around the periphery of the Pacific anticyclone and intensified in the Gulf of Alaska. Many of these storms plunged southeastward through western North America into the mean trough in southwestern United States. From here the principal track extended across the central Great Plains, Ohio Valley, and Middle Atlantic States, well south of the normal position. This southward depression of the principal storm track, together with the unusually low frequency of storminess in eastern Canada, further illustrates the blocking type of circulation which prevailed in eastern North America during March.

The high frequency of cyclones in the United States produced heavy precipitation over most of the country. Much of this fell in the form of snow (Charts IV and V). In the Sierra Nevada and Rocky Mountains a near-record snow pack was recorded. Blizzard conditions were frequent in north central United States, where some roads were blocked and it was necessary to supply isolated families and cattle with food by airlift operations. Precipitation was also quite abundant throughout eastern United States in the abnormally strong southwesterly flow ahead of a deep mean trough at 700 mb. At times, brief intrusions of maritime tropical air in advance of migratory storms produced destructive thunderstorms and tornadoes in the South.[2]

In southern portions of Texas and New Mexico there was a marked deficiency of precipitation. This condition accompanied unusually strong dry foehn winds and might be considered a good example of "rain shadow". Throughout this area numerous damaging dust storms were reported. Precipitation was also generally subnormal along the northern border of the United States where storms were less frequent than usual.

The anomalies of surface temperature shown in Chart I indicate that cold weather prevailed over most of the United States. The most extreme departures were found in the West behind the upper level mean trough and in the region of the lowest height anomalies and were produced by an almost uninterrupted flow of cold air from the northern Pacific reinforced at intervals by Canadian Polar air masses. Sub-zero minima occurred

[2] For further details see adjoining article by Carr.

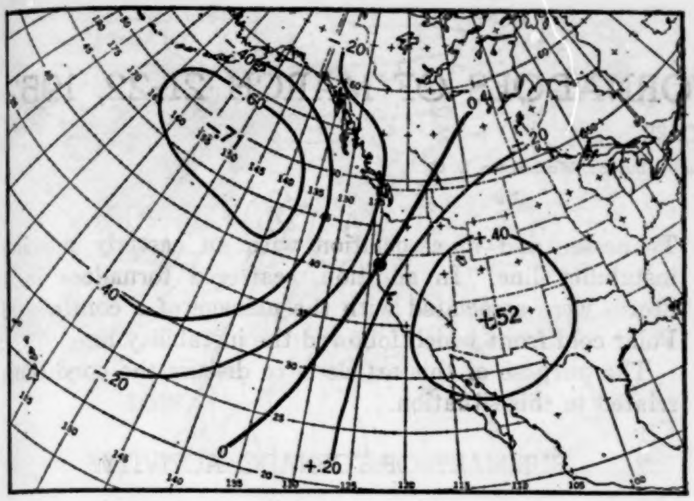

FIGURE 3.—Correlation field between 5-day mean surface temperature anomaly in winter at Eureka, Calif. (location shown by heavy black circle) and simultaneous 5-day mean 700-mb. height anomaly at standard intersections of latitude and longitude. The lines of equal correlation coefficient are drawn at intervals of .2. Centers of maximum and minimum correlation are labeled with highest observed coefficient value.

on several mornings in the Northern Rockies, and the daily minimum temperature record for March was broken at the Salt Lake City Airport. Previous studies [2] have shown that temperatures throughout the United States west of the Rocky Mountains are dependent on the 700-mb. height anomalies in the northern Pacific and Great Basin areas. For example, a high degree of correlation exists between the surface temperature anomaly at Eureka, Calif. and the 700-mb. height anomalies in these two widely separated regions, as illustrated in figure 3. Since the centers of highest correlation in figure 3 are in approximately the same position as the centers of 700-mb. height anomaly in figure 1, it is reasonable to expect that the circulation pattern of March 1952 would give cold weather in western United States.

In the northern central portions of the United States the easternmost extension of the cold temperature anomalies approximates the longitude of the mean 700-mb. trough line. This is a common relationship, with cold anomalies behind a mean trough and warmer anomalies in front of the trough line. At middle and low latitudes the cold anomaly boundary was considerably farther eastward than the trough line. This often happens when the trough has a large tilt from northeast to southwest with a broad area of cyclonic curvature ahead of the trough. In these cases the below-normal temperatures frequently extend a considerable distance ahead of the mean 700-mb. trough line.

In the eastern United States temperatures averaged a few degrees above normal. Warm weather in the Northeast was associated with a higher than normal frequency of onshore winds from the Atlantic Ocean which is warmer than the continent during March. The area of above-normal temperatures in the Southeast was associated with a ridge at 700 mb. along the East Coast. Although this ridge was weaker than normal, it was strong enough relative to the trough in the West to allow the advection of some warm maritime air masses into southeastern United States.

This month's circulation patterns and the associated anomalies were relatively extreme and persistent. They were essentially a continuation of patterns which had become established in the second half of the preceding month in connection with the onset of a pronounced index cycle [3].

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A PRELIMINARY REPORT ON THE TORNADOES OF MARCH 21-22, 1952

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INTRODUCTION

On March 21, 1952, at 1430 CST, Dierks, Ark., reported a tornado which, it turned out, was the precursor of an intense outbreak of a series of tornadoes, beginning 3 hours later over northeastern Arkansas and western Tennessee and, during the following 23 hours, over portions of Alabama, Kentucky, Louisiana, and Mississippi. Arkansas was hardest hit as indicated by estimates of property damage reaching 25 million dollars. The death toll for the 6 States was placed at about 200 and the injured at over 1,000 people.

The greatest concentration of violent storms occurred in the warm, moist, maritime tropical air just to the south of a quasi-stationary front over portions of Arkansas and Tennessee and in association with an easterly moving instability line. In addition, scattered tornadoes in 4 States were associated with the passage of a continental Polar cold front which followed the instability line.

The purpose of this article is to discuss the conditions related to this situation.

SUMMARY OF TORNADO ACTIVITY

The surface charts (figs. 1, 2, 6, and 7) depict the surface conditions during the tornado period and at times when upper air soundings were available. On figure 1 for 9:30 a. m. CST (1530 GMT) areas or points where tornadoes were reported are shown by dots. The dot in southwestern Arkansas, at Dierks, represents the first reported storm

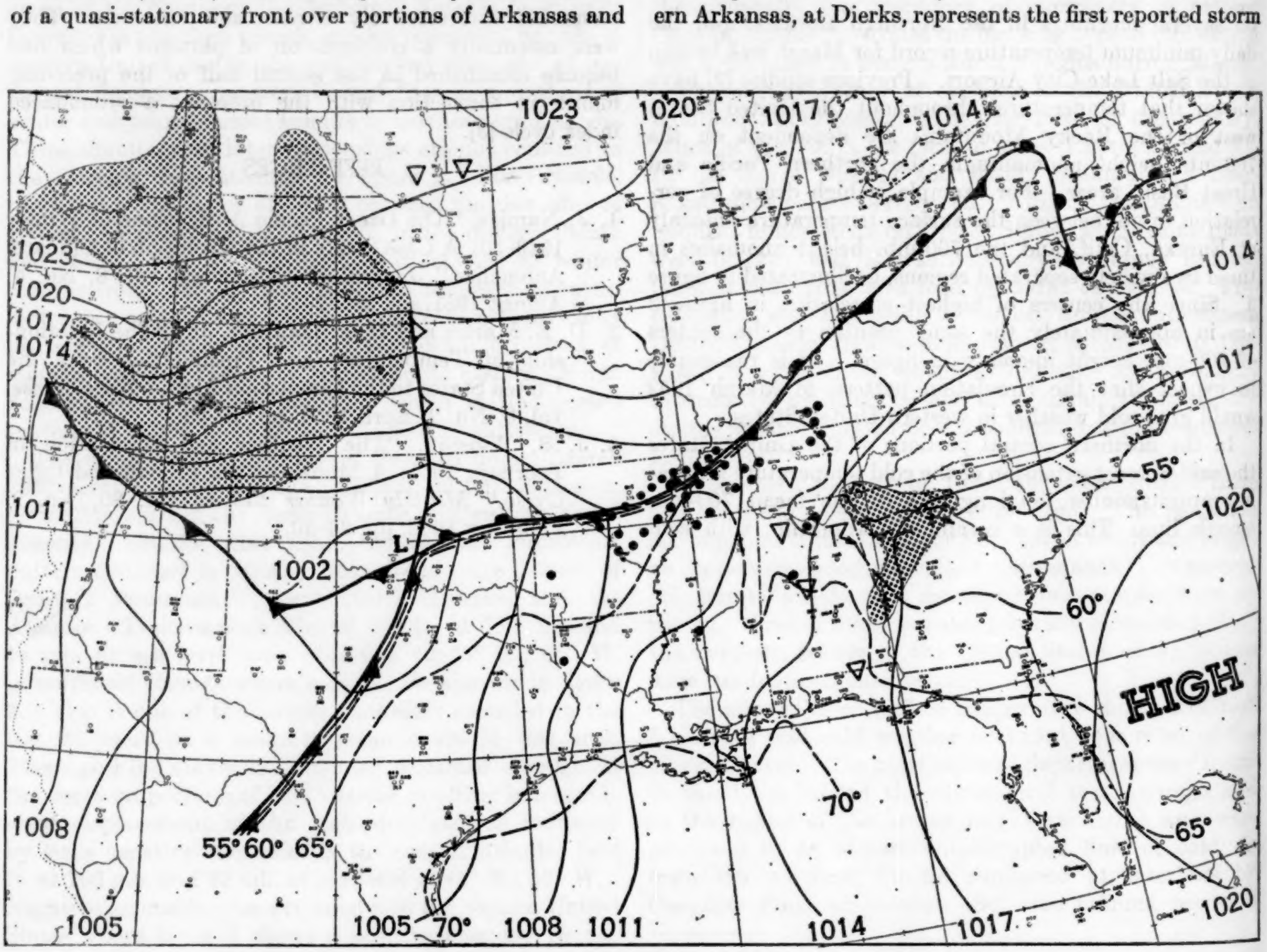

FIGURE 1.—Surface chart, 1530 GMT, March 21, 1952. Shaded areas, shower and thunderstorm symbols indicate precipitation in progress. Dots or dotted areas indicate approximate location of reported tornadoes. Isopleths (dashed lines) of dew point are at intervals of 5° F.

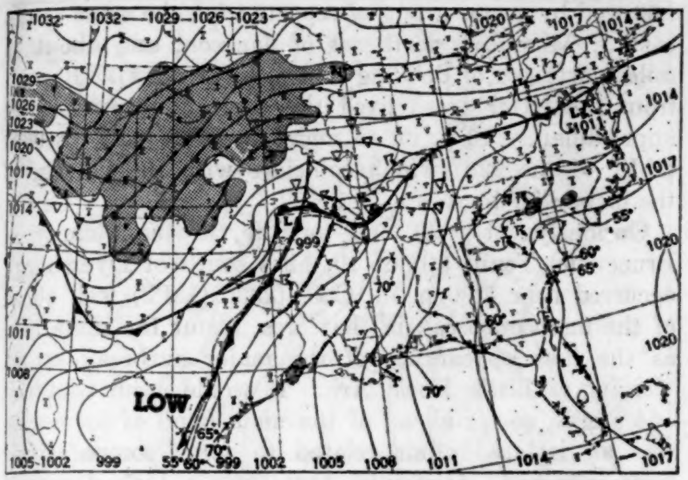

FIGURE 2.—Surface chart, 0030 GMT, March 22, 1952.

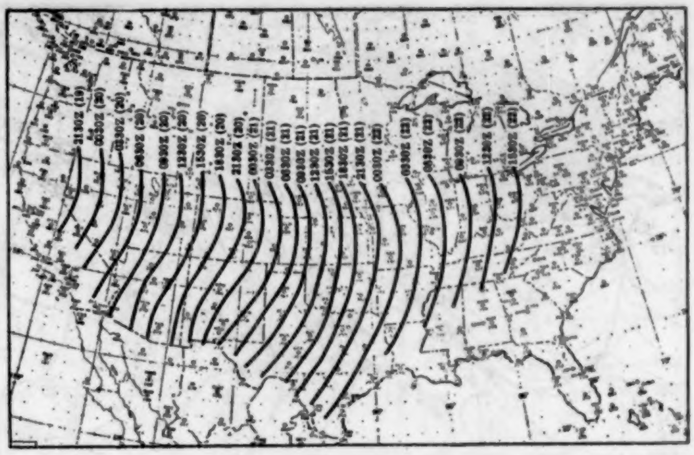

FIGURE 4.—Position of the maritime Polar (Pacific) front at 3-hourly intervals, March 19-22, 1952. Time in GMT (Z).

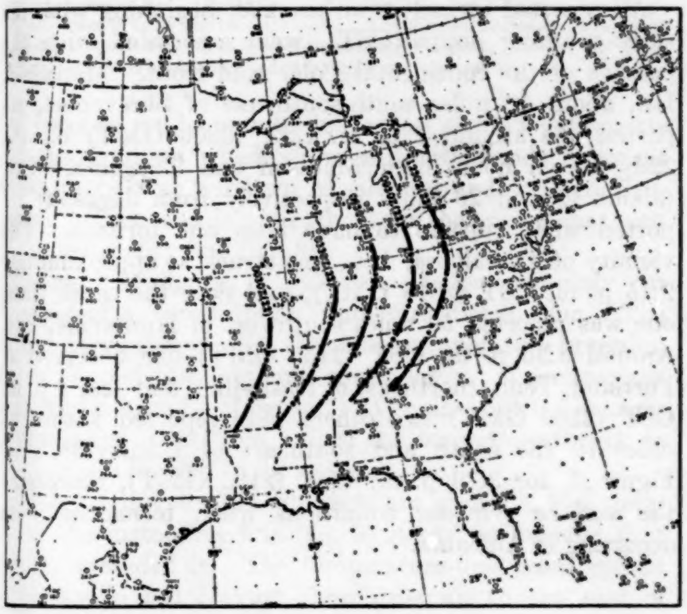

FIGURE 3.—Position of the instability line at 3-hourly intervals, March 22, 1952. Time in GMT (Z).

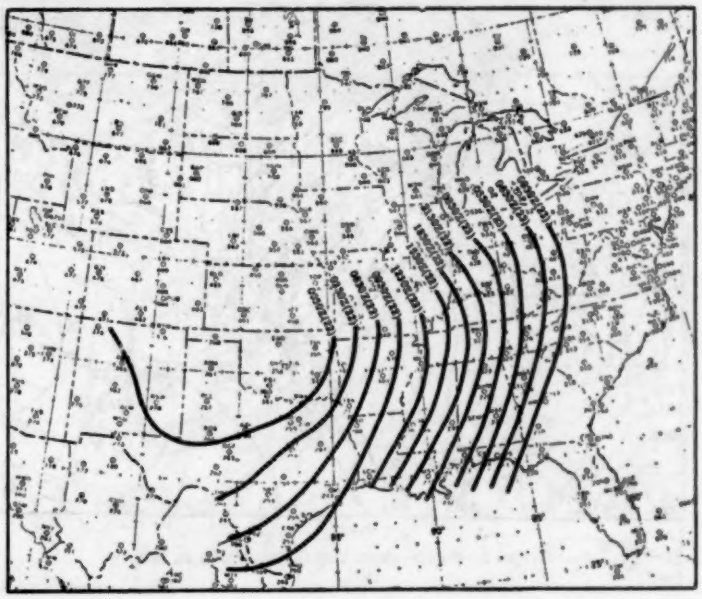

FIGURE 5.—Position of the continental Polar front at 3-hourly intervals, March 19-22, 1952. Time in GMT (Z).

presumably associated with the instability line which was just forming. Tornadoes within the oblong area from central Arkansas northeastward to Tennessee were associated with the passage of the instability line as were tornadoes in 3 other areas, one southeast of Memphis, another northeast of Jackson, Tenn., and one storm 50 miles northeast of Bowling Green, Ky. The dots, or areas, in Louisiana, Mississippi, Alabama, the area northeast-to-east of Bowling Green, Ky., and the small region northeast of Nashville, Tenn., represent locations of tornadoes associated with the continental Polar cold front.

Approximately 5 hours before the first tornado, the major low center was near Ft. Sill, Okla., as shown by figure 1. On this map the distribution of surface dew point temperatures is outlined, the axis extending northward along the Mississippi River toward Memphis where it bends northeastward between the stationary front and the southern Appalachians.

With the passage of the Low toward southwestern Missouri, the tightening of the pressure gradient, cooling behind the instability line, and solar heating during the afternoon, the weather became considerably more active as shown by figure 2, which is for nine hours after the time of figure 1. By this time, the instability line was well developed and attended by severe thunderstorm activity, and north-northeast of Little Rock, Ark., tornadoes were in progress.

The gradient winds were 30–35 m. p. h. from the south to south-southwest over Arkansas and Louisiana, and were from the south-southeast over Mississippi. These areas

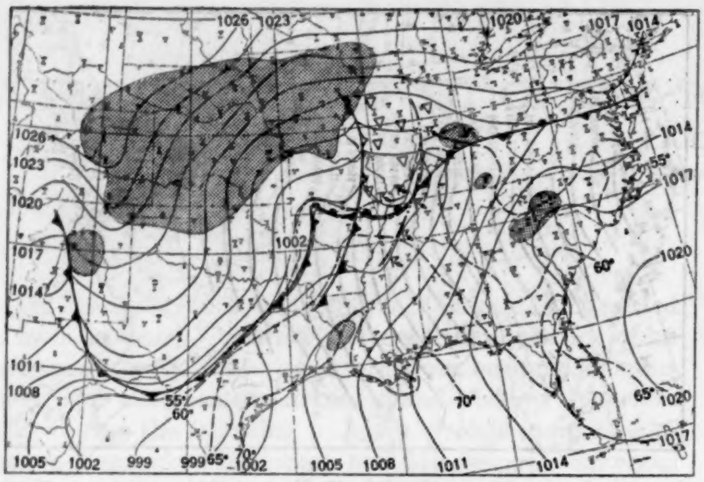

FIGURE 6.—Surface chart, 0330 GMT, March 22, 1952.

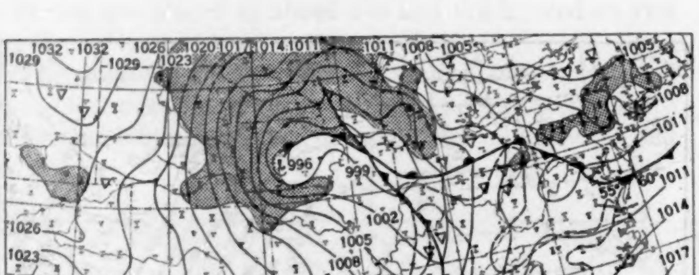

FIGURE 7.—Surface chart, 2130 GMT, March 22, 1952.

coincide with the area covered by the 65° dew point line (fig. 2). Together, these two facts reveal a strong surface transport of moist air toward the low center. One hour after this map, tornadoes were reported in the region of northeastern Arkansas close to the Mississippi River, generally west and northwest of Memphis. The 3-hourly histories of the instability line and of two cold fronts of the system are presented by figures 3, 4, and 5 respectively. The first cold front (fig. 4) separating mT and mP (Pacific) air, and the second (fig. 5) lying between the mP and colder cP air.

The surface synoptic conditions just after the tornadoes began in western Tennessee, the second hardest hit of the 6 States, is illustrated by figure 6, for 9:30 p. m. CST (0330 GMT). The first reports of tornadoes in Tennessee came from the general region of Dyersburg at approximately 8:30 p. m. CST (0230 GMT of the 22d), followed by a new group of reports from the areas southeast of Memphis, northeast of Jackson, and about 50 miles northeast of Bowling Green, Ky., (fig. 1). Reports from the latter areas fixed the time of occurrences as approximately 10 p. m. to midnight CST (0400 to 0600 GMT of the 22d) which coincides with the passage of the instability line.

Curiously, at least one tornado, in the vicinity of Bruceville, Tenn. (about 10 miles south of Dyersburg), occurred near 5:30 p. m. CST (2330 GMT) well ahead of the main outbreak in that area, about the same time as the first appearance of the major outbreak in the vicinity of Little Rock, Ark. It would seem that this one storm, so far ahead of the main band of tornadoes, was an isolated affair related to some comparatively local influence. Certainly, there was a high degree of conditional instability at the time, as will be discussed later.

All reported tornadoes on the 22d, beginning with the early morning hours (CST), were associated with the passage of the continental Polar cold front. Mansfield, La., about 12 miles south-southwest of Shreveport, reported one around 2 a. m. CST (0800 GMT) on the 22d. Seven hours later Madison and Tougaloo, Miss. (about 12 and 20 miles respectively from Jackson) reported what appears to have been one tornado. The vicinity of Tuscaloosa, Ala., was struck at approximately 2:15 p. m. CST (2015 GMT), and near the same time, one was reported 50 miles southwest of Huntsville, Ala. Around 3:30 p. m. CST (2130 GMT) one occurred at Portland, Tenn. (northeast of Nashville), and near 4 p. m. CST (2200 GMT) two others were reported within 25 miles to the south and southeast of Huntsville, Ala. Figure 7, for 3:30 p. m. CST (2130 GMT), represents the surface synoptic conditions when tornadoes were occurring in Alabama.

THE VERTICAL STRUCTURE

The knowledge of the vertical structure of temperature, moisture, and wind is of considerable importance in tornado studies. Unfortunately in this case, a detailed study of wind structure was not possible because of the absence of pilot balloon observations in the zone of severe weather. However, the regular RAWIN observations at 0300 GMT, on March 22, present enough information to be useful in this case study. Figures 8, 9, and 10 in connection with the corresponding surface map (fig. 6) are intended to convey the vertical picture at 0300 GMT, close to the time of the maximum tornado activity. The 850-mb. chart (fig. 8) suggests the vertical extent of the moist tongue as shown, for example, by the area enclosed within the 10° C. dew point line. As on the surface chart (fig. 6), there is also strong northward advection of moist air at the 850-

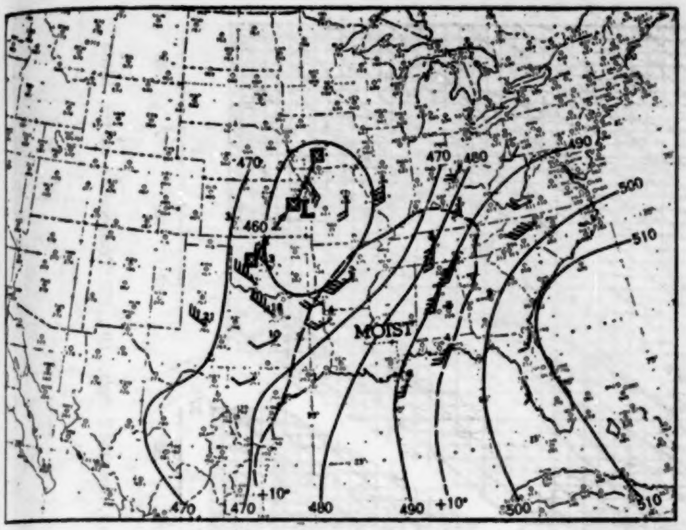

FIGURE 8.—850-mb. chart, 0300 GMT, March 22, 1952. Contours (solid lines) at intervals of 100 geopotential feet. Dashed line is 10° C. dew point line. Barbs on wind shafts indicate speed in knots (full barb=10 knots). Numbers near station circles represent spread (in °C.) between the air temperature and the dew point. Blocked "X" shows positions of Low 12 hours before and after the present map position.

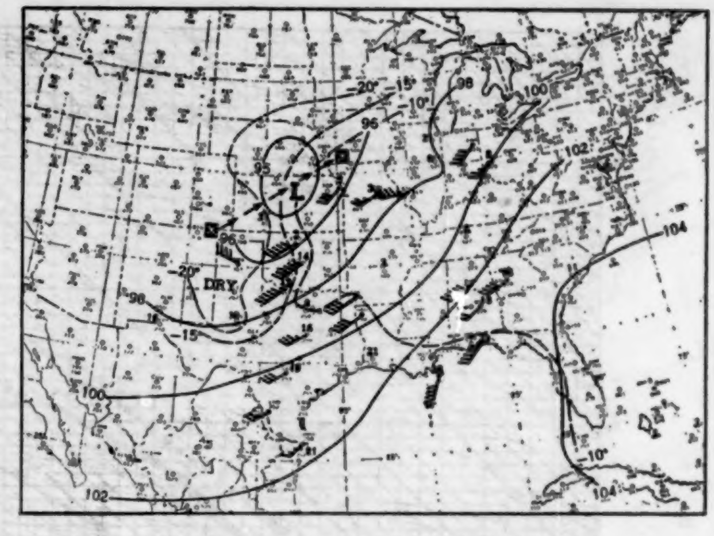

FIGURE 9.—700-mb. chart, 0300 GMT, March 22, 1952. Contours (solid lines) at intervals of 200 geopotential feet except 100 feet for contour line around Low. Selected lines of equal dew point at 5° C. intervals (dashed lines).

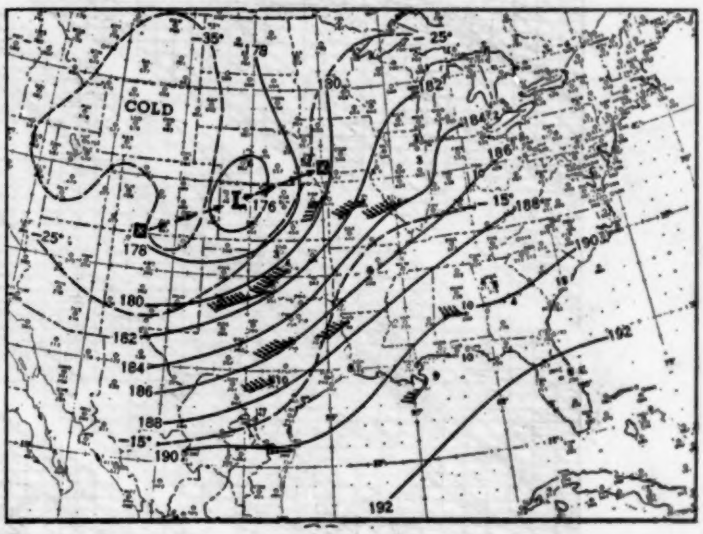

FIGURE 10.—500-mb. chart, 0300 GMT, March 22, 1952. Contours (solid lines) at intervals of 200 geopotential feet. Isotherms (dashed lines) for selected values at 5° C. intervals.

mb. level as can be seen by inspection of the wind reports and the gradient which show southerly winds in excess of 50 knots over northern Mississippi and western Tennessee. This area is approximately the region just east of the instability line (fig. 3).

Curve 1 of figure 11 (A) is a particularly clear cut example of a "pre-tornado" moisture distribution. The dotted curve (fig. 11 (B)) shows the temperature inversion which capped this low level moist layer. A comparison of curves 2, 3, and 4 of figure 11 (A) points out the changes in the moist layer from before the tornado outbreak to conditions following in its wake.

Even though the 700-mb. data are sparse in the vicinity of the instability line (fig. 9) it can be inferred that dry air preceded it. The temperature-dew point spread at Nashville and Dayton show drier air to the east of the line. From the reports at this level it is possible to note two facts, namely, the wind speed shear from 850 mb. to 700 mb. and the apparently strong advection of dry air indicated by the dew point lines and the wind flow over the western half of Oklahoma. The region of driest air is behind the surface, continental Polar cold front which produced tornadoes later on as mentioned elsewhere.

The band of strong southwest winds at the 700-mb. level is also evident at the 500-mb. level (fig. 10) but displaced more toward the west with the line of maximum winds located along a line from Oklahoma City, Okla., toward Columbia, Mo. This position, incidentally, just about coincides with the position of the 300-mb. jet stream axis, along which there is a band of winds having speeds of about 120 knots over a 60-mile wide strip just east of Tulsa which narrowed to a point at the intersection of the northwestern corner of Arkansas and the southwestern corner of Missouri. Winds at this level exceed 100 knots over a band extending from Little Rock to Wichita, Kans.

Returning to figure 10, the 500-mb. chart for 0300 GMT of the 22d, it can be seen that wind speeds over the tornado area increased sharply with height between 700 mb and 500 mb., but without change of direction. There is no strong cold advection at the 500-mb level in the region where tornadoes were occurring. Figures 8, 9, and 10 show that the contours aloft were straight when tornado conditions existed in western Tennessee and western Kentucky, but a comparison with previous charts shows that the contours were changing from less cyclonic to more cyclonic, indicating advection of cyclonic vorticity into that region.

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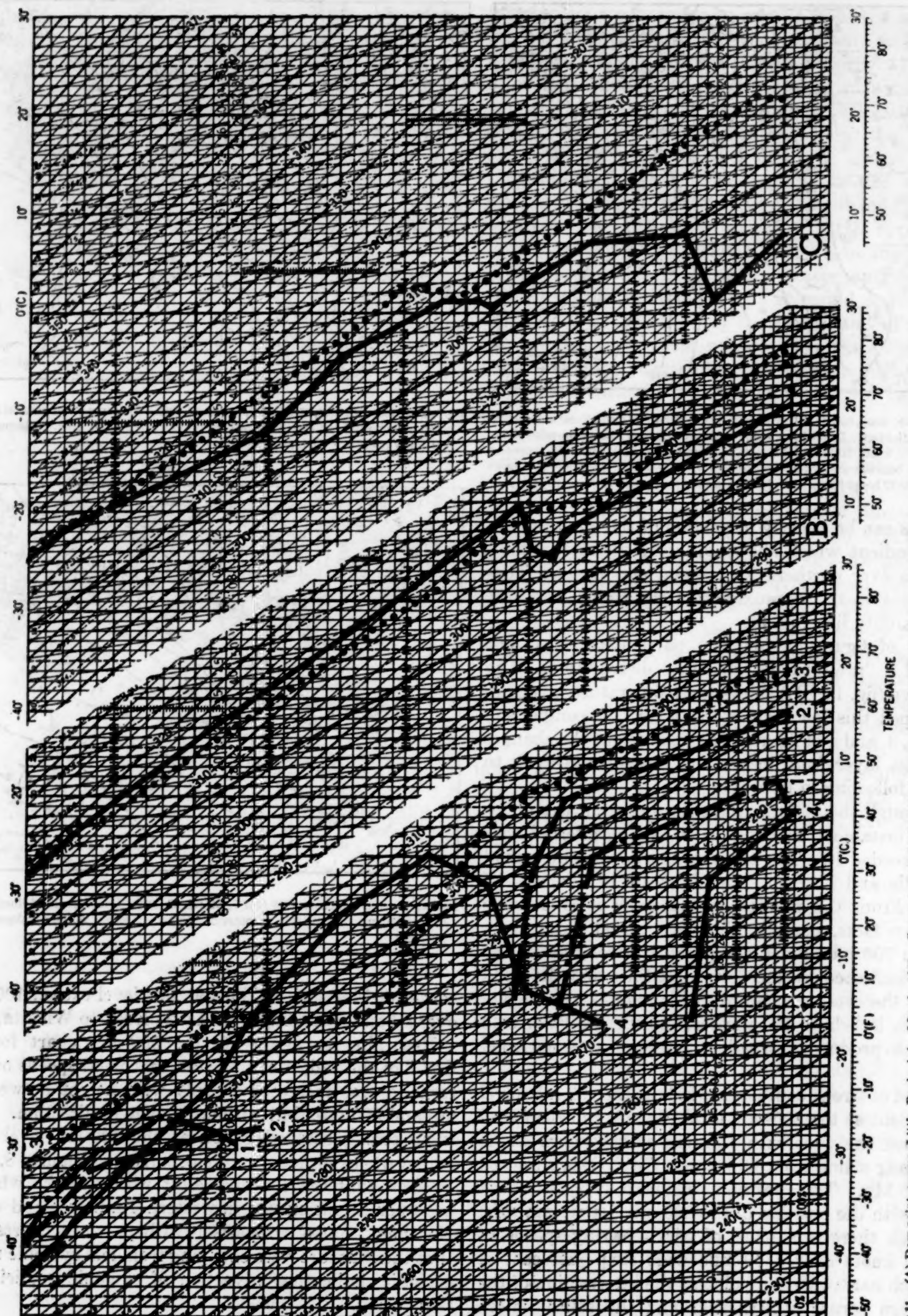

FIGURE 11.—(A) Dew point curves, Little Rock, Ark., March, 1952. Curve 1, 0300 GMT, (21st), curve 2, 1500 GMT (21st), curve 3, 0300 GMT (22d), and curve 4, 1500 GMT (22d). (B), (C) Temperature curves, Little Rock, Ark., March 21 and 22, 1952, respectively. Dotted curve, 0300 GMT; solid curve, 1500 GMT.

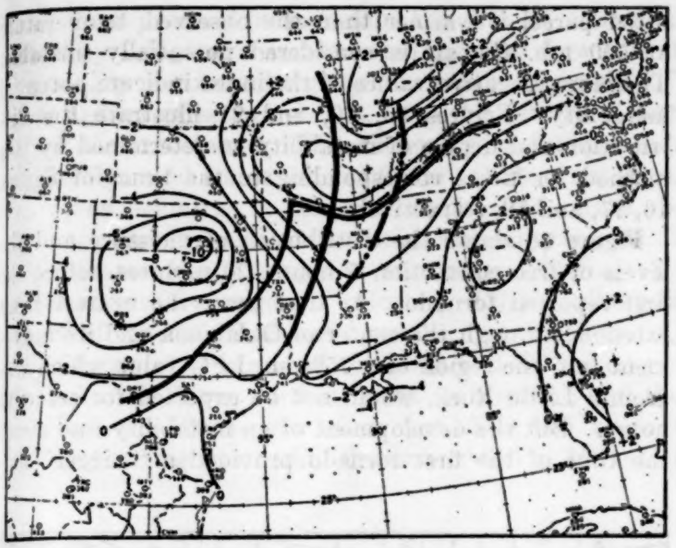

FIGURE 12.—850-mb. 12-hour temperature change chart, 1500 GMT March 21 to 0300 GMT March 22, 1952. Solid lines represent change at intervals of 2° C. Heavy solid lines show 0330 GMT surface frontal positions.

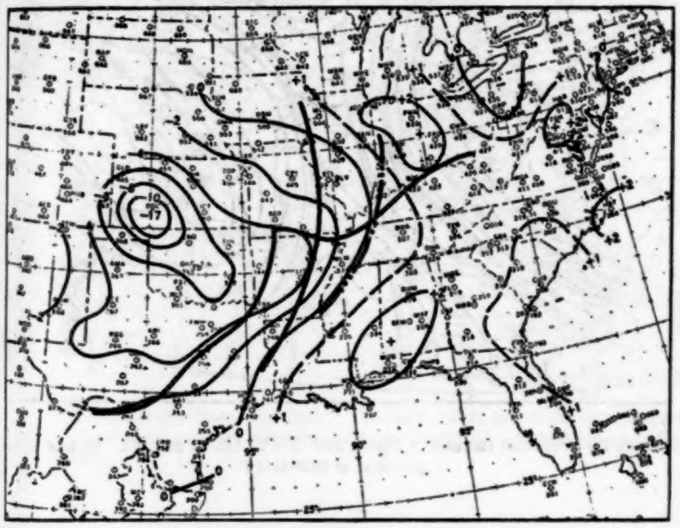

FIGURE 13.—700-mb. 12-hour temperature change chart, 1500 GMT March 21 to 0300 GMT on March 22, 1952.

The 12-hour temperature change charts, figures 12, 13, and 14 for the 850-, 700-, and 500-mb. levels respectively, show important changes in the stability of the air between 1500 GMT on the 21st and 0300 GMT on the 22d. It is significant that, within the area where tornadoes were occurring at the end of the 12-hour period, temperatures had increased at 850 mb. and had decreased at 700 mb. showing a decrease in the vertical stability.

Figures 12, 13, and 14 also illustrate the ineffectiveness of the maritime Polar front in producing tornadoes. In particular, figure 13 shows the strongest gradient of temperature change near the tornado zone and between the instability line and the maritime Polar front. In other words, with the passage of the instability line there was a marked change to cooler at 700 mb. over the major tornado area of Arkansas and Tennessee, but the arrival of

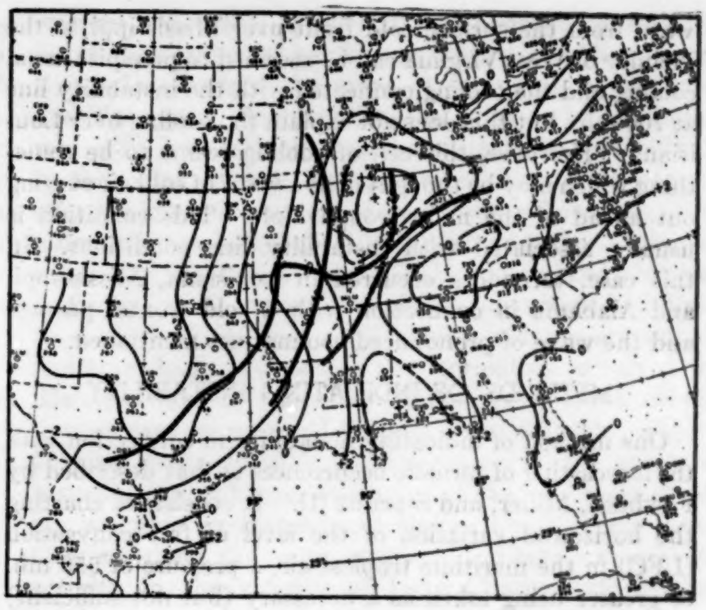

FIGURE 14.—500-mb. 12-hour temperature change chart, 1500 GMT March 21 to 0300 GMT on March 22, 1952.

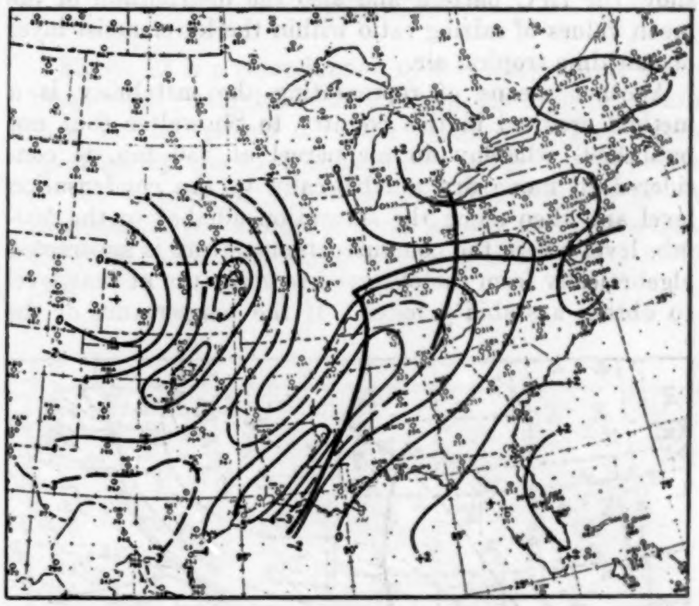

FIGURE 15.—700-mb. 12-hour temperature change chart, 0300 GMT March 22 to 1500 GMT on March 22, 1952. Heavy solid lines show 1530 GMT surface frontal positions.

the maritime Pacific front was not accompanied by further cooling at the 700-mb. level.

Figure 14 shows warming at the 500-mb. level over the same area which cooled at 700 mb. This warming could possibly be explained as the result of heat being carried upward from below by the intense convective activity.

Figure 15 shows the 700-mb., 12-hour temperature change in the period ending 1500 GMT of the 22d. An interesting feature of this chart is the off-shoot (for the most part west of the surface cold front) extending northeastward from Lake Charles, La. The bulging northeast-

ward from the surface cold front over Mississippi to the vicinity of West Virginia can be ascribed to precipitational cooling and the cooling connected with the instability line at 700 mb., but this does not explain the cooling over Louisiana. However, this cell of cooling seems to be something which may be thought of as a wave of cold air surging out ahead of the main trough aloft. This condition is usually associated with instability line conditions. In this case, tornadoes occurred in Louisiana, Mississippi, and Alabama in connection with a cold frontal passage and the wave of pronounced cooling just mentioned.

METHODS OF INDICATING INSTABILITY

One method of indicating instability in connection with the forecasting of tornado occurrences is that described by Fawbush, Miller, and Starrett [1]. It consists of charting the horizontal variation of the level of free convection (LFC) in the maritime tropical air, a pressure of 650 mb. or greater being taken as a necessary (but not sufficient) condition for the occurrence of tornadoes. Figures 16, 17, and 18, the potential instability charts for 1500 GMT on the 21st and 0300 GMT and 1500 GMT on the 22d, show the LFC pattern and also the distribution of the mean values of mixing ratio within the lower moist layer of maritime tropical air.

Another means of representing the instability is a method credited in this country to Showalter (but not published) whereby an air parcel at 850 mb. is considered to move dry adiabatically to the condensation level and then along the saturation adiabat to the 500-mb. level where the computed temperature is subtracted algebraically from the observed temperature at that level to obtain a stability index. If the temperature of the lifted parcel is warmer than the observed temperature at 500 mb. the air is considered potentially unstable. Therefore, negative values of the index indicate potential instability. Figures 19, 20, and 21 illustrate the distribution and degree of instability as determined by this method for times corresponding to the times of figures 16, 17, and 18, respectively.

Figure 16 shows the distribution of moisture and the levels of free convection 5 hours, 20 minutes before the first reported tornado. At that time, the nearest front extended through the center of Oklahoma and its movement into the region of a 750-mb. LFC value which was around Little Rock, would not be expected for some 12 hours. But the development of an instability line about the time of the first tornado provided a "trigger" suf-

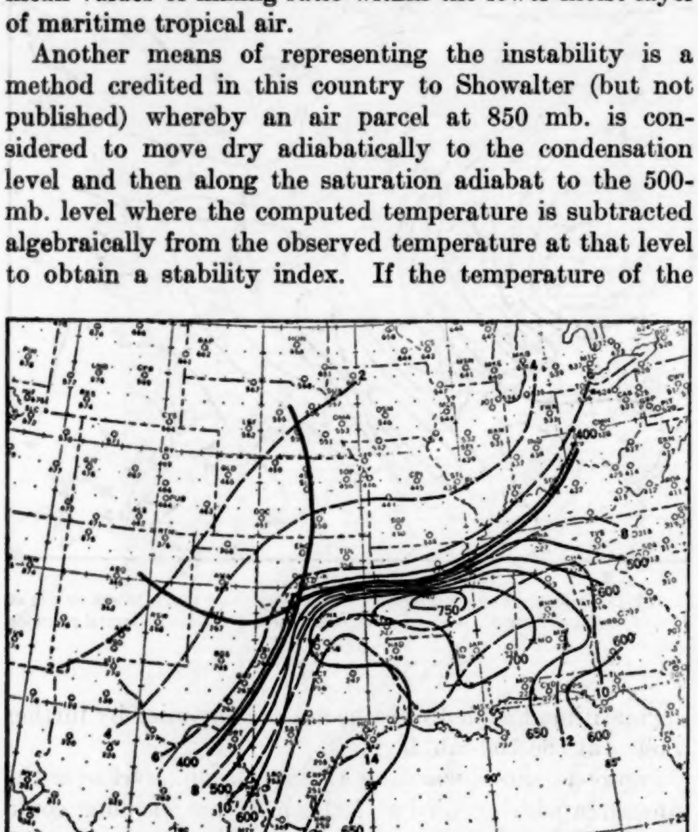

FIGURE 16.—Potential Instability Chart [1], 1500 GMT, March 21, 1952. Heavy solid lines are surface frontal positions at 1530 GMT; dashed lines connect points of equal mean mixing ratio (g./kg.) at 2-gram intervals. Lighter solid lines connect points of equal pressure of the free convection level (expressed in mb.).

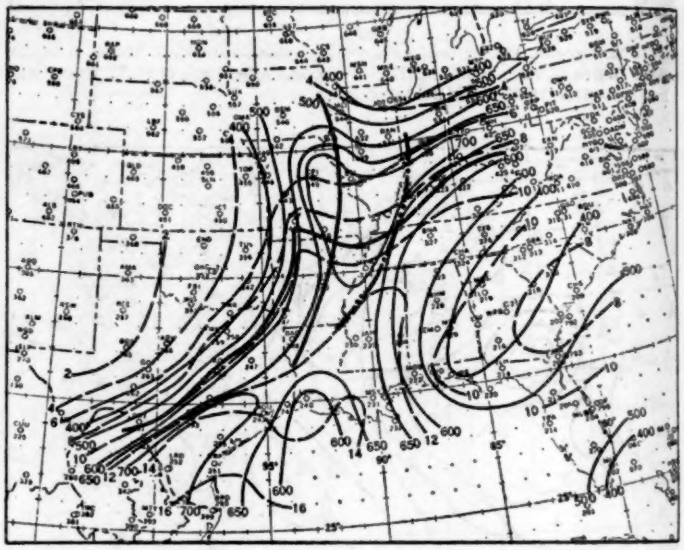

FIGURE 17.—Potential Instability Chart, 0300 GMT, March 22, 1952. Surface frontal positions at 0330 GMT.

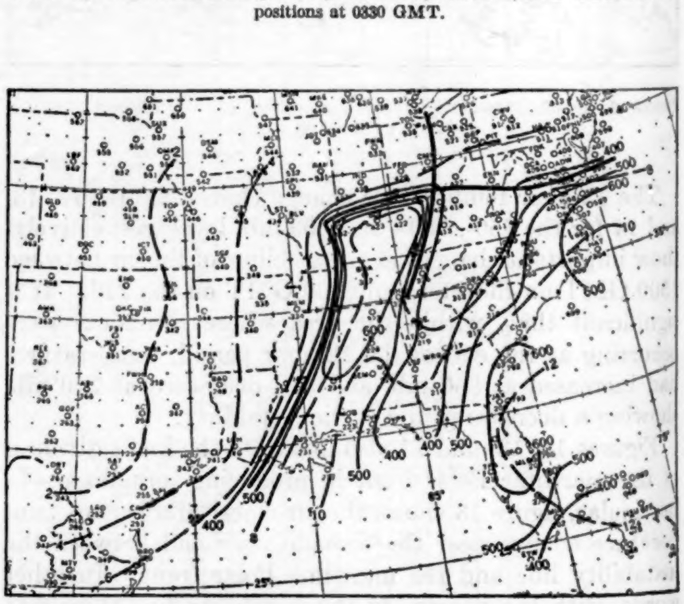

FIGURE 18.—Potential Instability Chart, 1500 GMT, March 22, 1952. Surface frontal positions at 1530 GMT.

ficient to produce tornadoes in the area of marked instability. Figures 4 and 16 taken together show that the instability line moved through the region where the LFC had highest pressures, that is, from the vicinity of Little Rock northeastward. The Showalter instability index chart, figure 19 (same time as figure 16), does not appear to be as definitive in this case as the LFC areas, but it does show a band of potential instability across the Gulf States from Georgia to east central Texas. The area of greatest negative values (−4°) is quite a bit south of the critical area of figure 16.

In figure 17, the axis of the greatest LFC values runs from Laredo, Tex., northeastward to Memphis and then northward. The region where tornadoes had been, or were, occurring was within the area of 650 to 700 mb. in western Tennessee. Figure 20, the Showalter instability index chart, shows the extension northward of large negative values toward the areas of tornadoes in Arkansas and Tennessee. Incidentally, the value at Lake Charles was −8°, but, lacking frontal or instability line activity in that area, such a high degree of instability was ineffective in producing tornadoes. Twelve hours later, the potential instability chart (fig. 18) and the Showalter instability index chart (fig. 21) showed marked changes. In figure 18, the lowest level of free convection had lifted to a value of 640 mb. at Nashville and the amount of moisture had decreased. The tornadoes occurred in Alabama (fig. 1) when the surface cold front moved into an area where the LFC was about 600 mb. Figure 21 also shows considerable weakening of the potential instability in 12 hours, with most of the land areas showing a stable or increasingly stable index, except Lake Charles where the value was −5°. There was still no activity in the vicinity of Lake Charles sufficient to produce tornadoes.

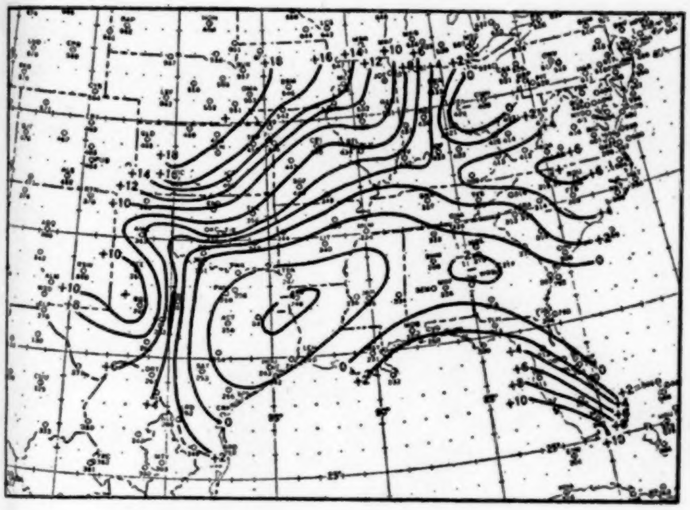

FIGURE 19.—Showalter Instability Index Chart, 1500 GMT, March 21, 1952. Isopleths (solid lines) of temperature difference at intervals of 2° C. Negative signs indicate instability.

PRESSURE CHANGES AT DYERSBURG, TENN., WITHIN TORNADO

Figure 22 is a reproduction of the barogram at Dyersburg, Tenn., March 21–23, showing the drop in pressure as a tornado passed over the barograph. The station, operated by the Civil Aeronautics Authority, is located at the airport on top of a hill. The average ground elevation of the airport is given as 334 feet above mean sea level, while the barograph is at a height of 337.75 feet.

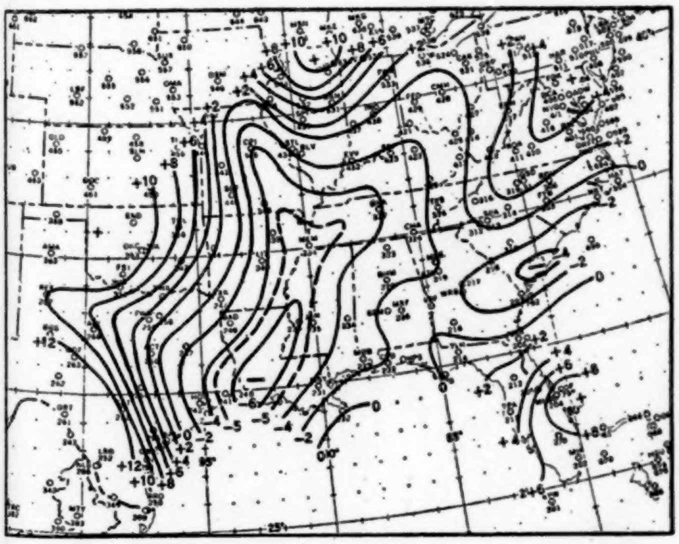

FIGURE 20.—Showalter Instability Index Chart, 0300 GMT, March 22, 1952.

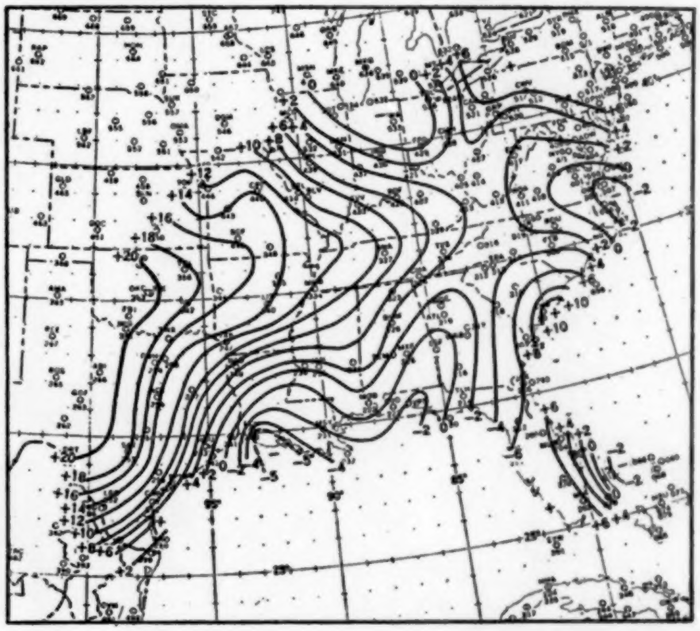

FIGURE 21.—Showalter Instability Index Chart, 1500 GMT, March 22, 1952.

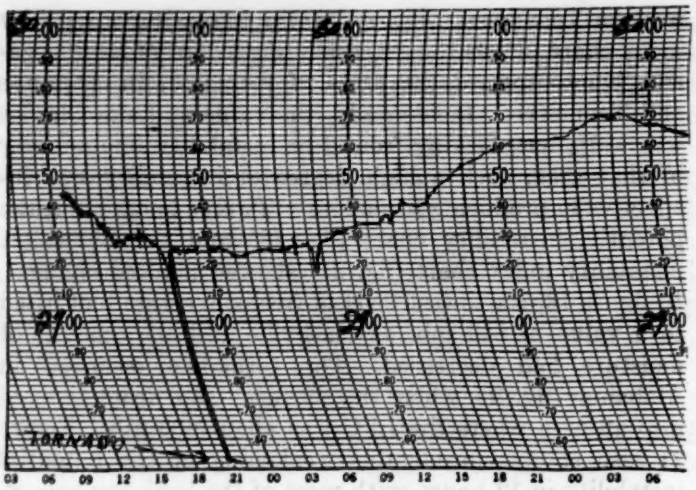

FIGURE 22.—Barogram trace made at Dyersburg, Tenn., March 21–23, 1952.

The center of the tornado (presumably taken as the middle of the path of destruction) passed 41 yards north of the barograph, and the barograph was 88 yards north of the south edge of the tornado as evidenced by destruction, according to information furnished by the Civil Aeronautics Authority. The destructive width of the tornado at that point was 258 yards. The decrease in pressure of approximately 0.65 inch with passage of the tornado, as shown on the trace, is perhaps somewhat less than the true drop because of probable lag in response of the instrument.

REFERENCE

1. E. J. Fawbush, R. C. Miller, and L. G. Starrett, "An Empirical Method of Forecasting Tornado Development", *Bulletin of the American Meteorological Society*, vol. 32, No. 1, January 1951, pp. 1–9.

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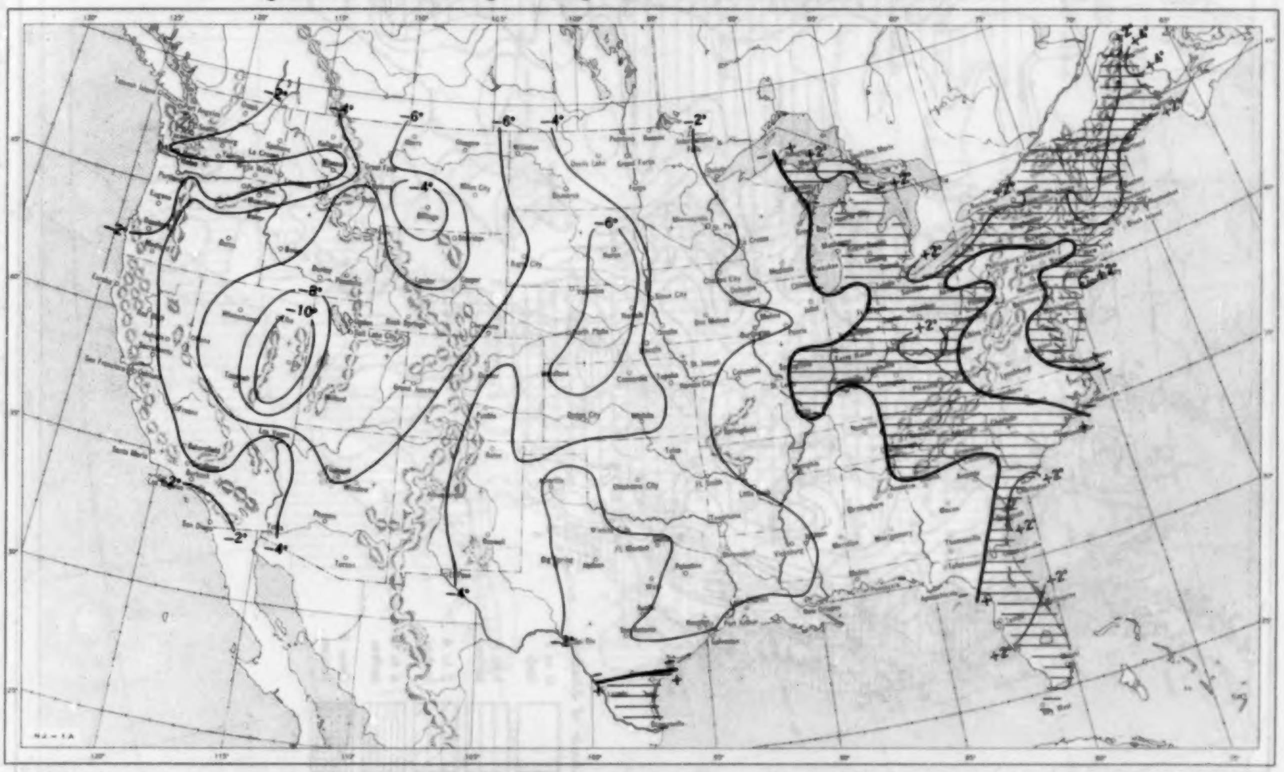
[illegible]

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

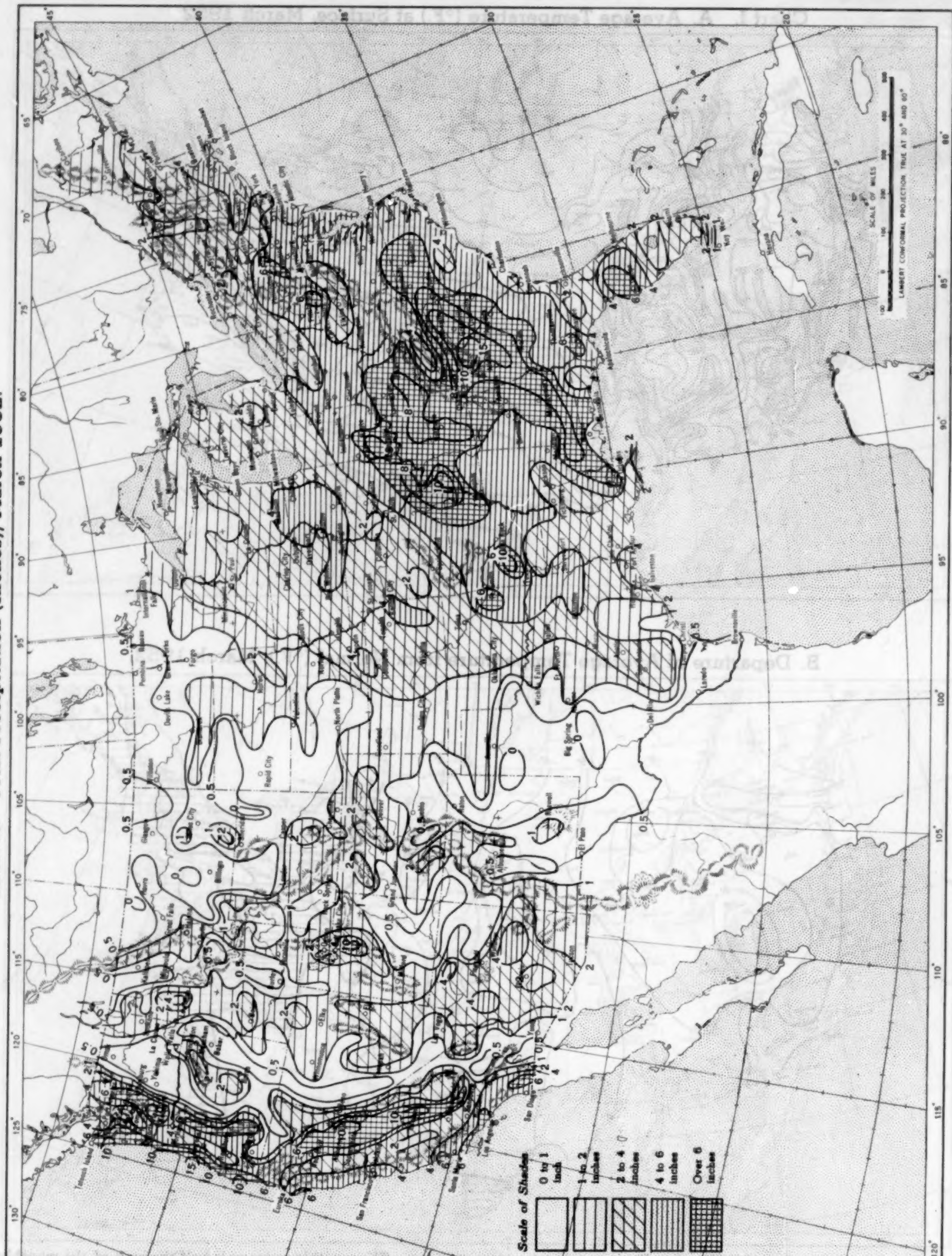
Chart I. A. Average Temperature (°F.) at Surface, March 1952.

B. Departure of Average Temperature from Normal (°F.), March 1952.



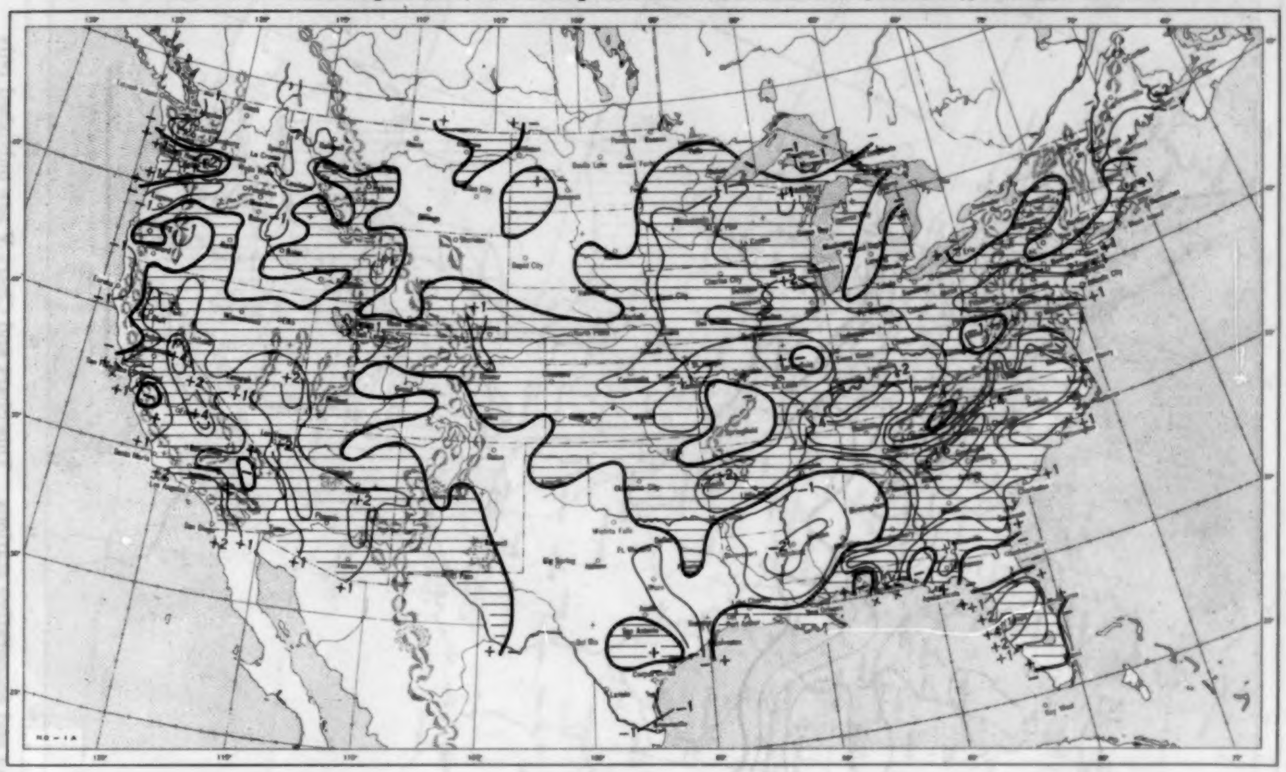
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), March 1952.

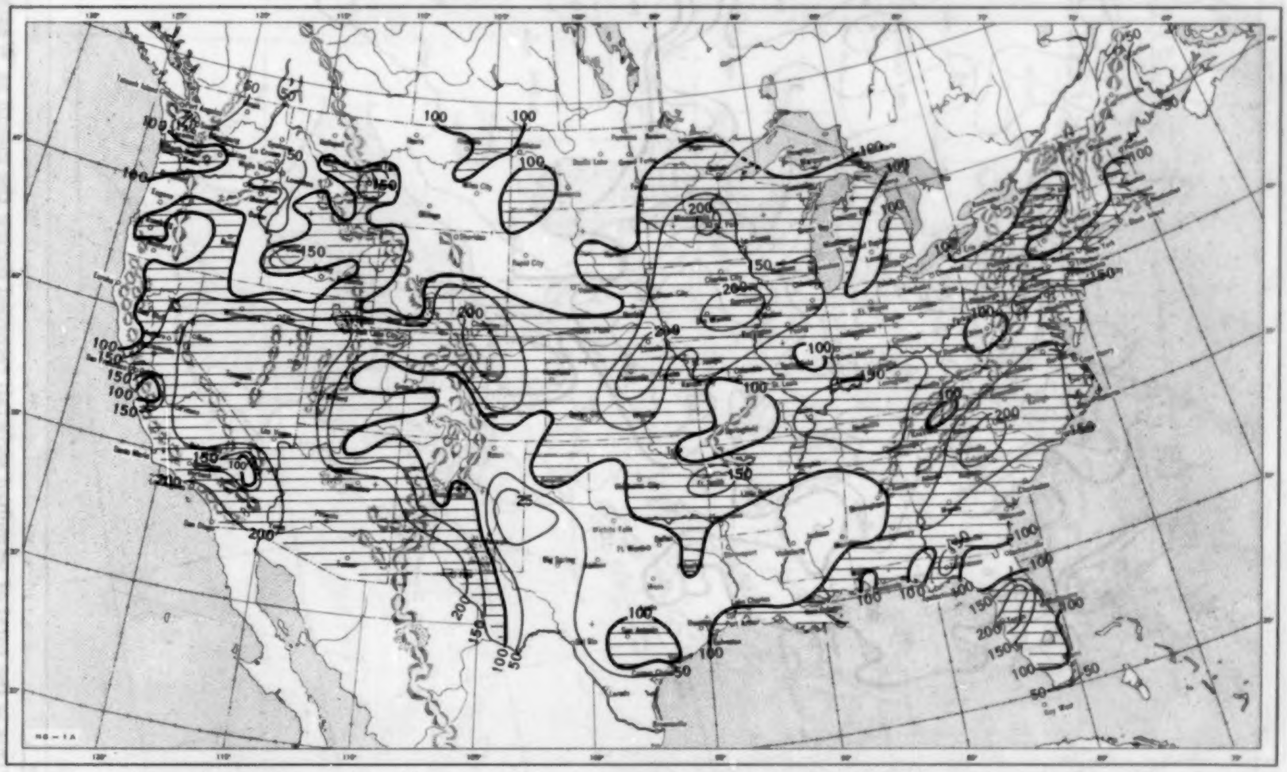


Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), March 1952.



B. Percentage of Normal Precipitation, March 1952.

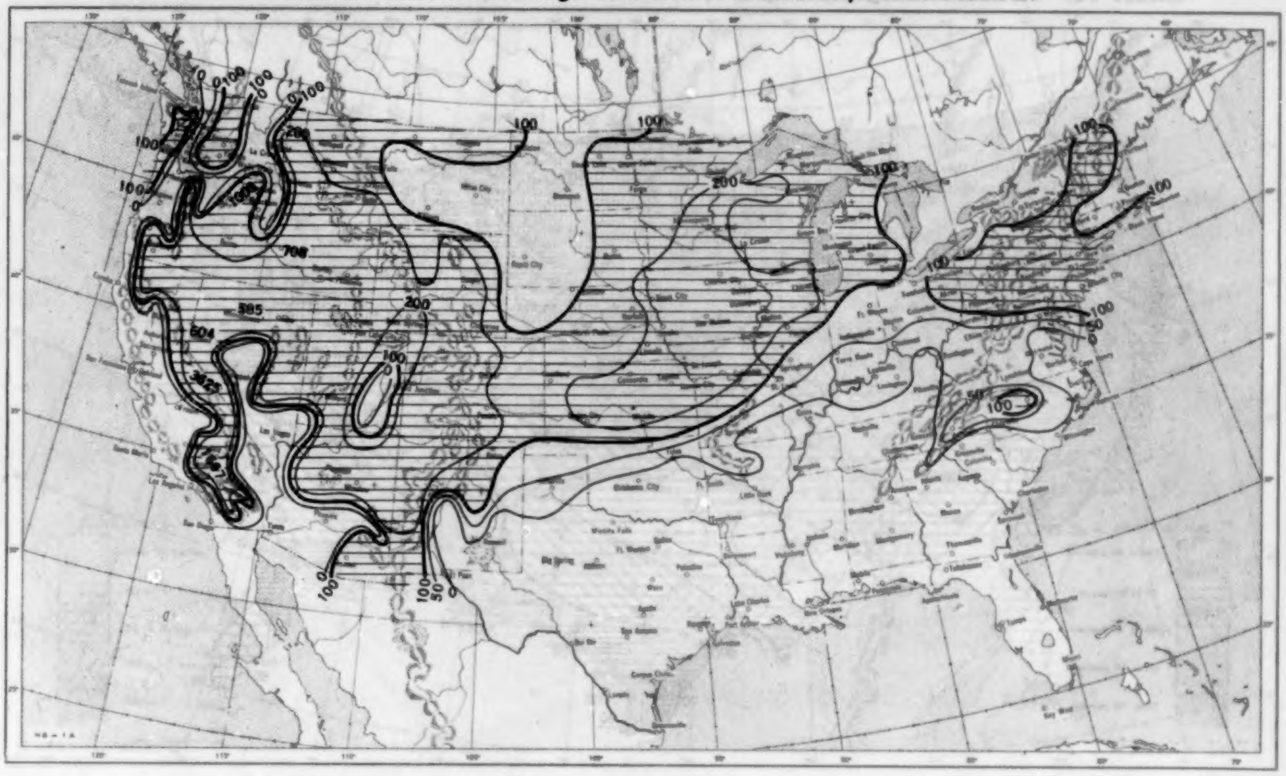


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

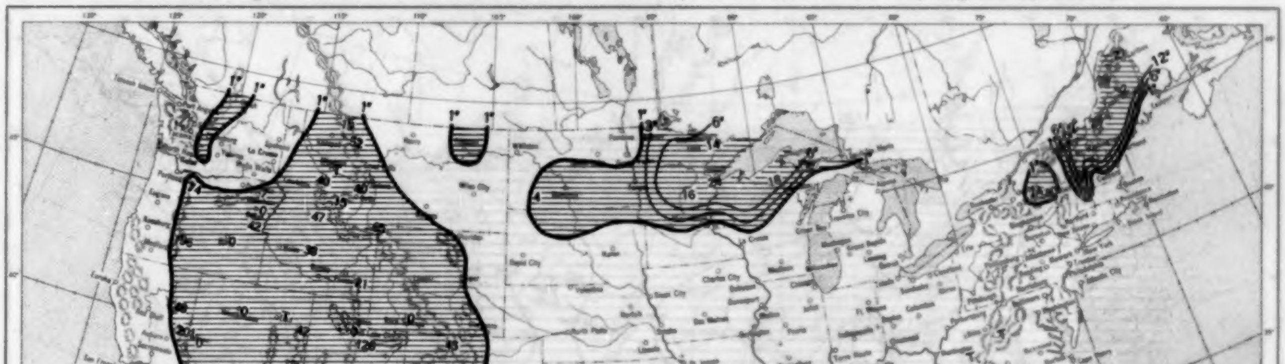
Chart IV. Total Snowfall (Inches), March 1952.

This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

Chart V. A. Percentage of Normal Snowfall, March 1952.

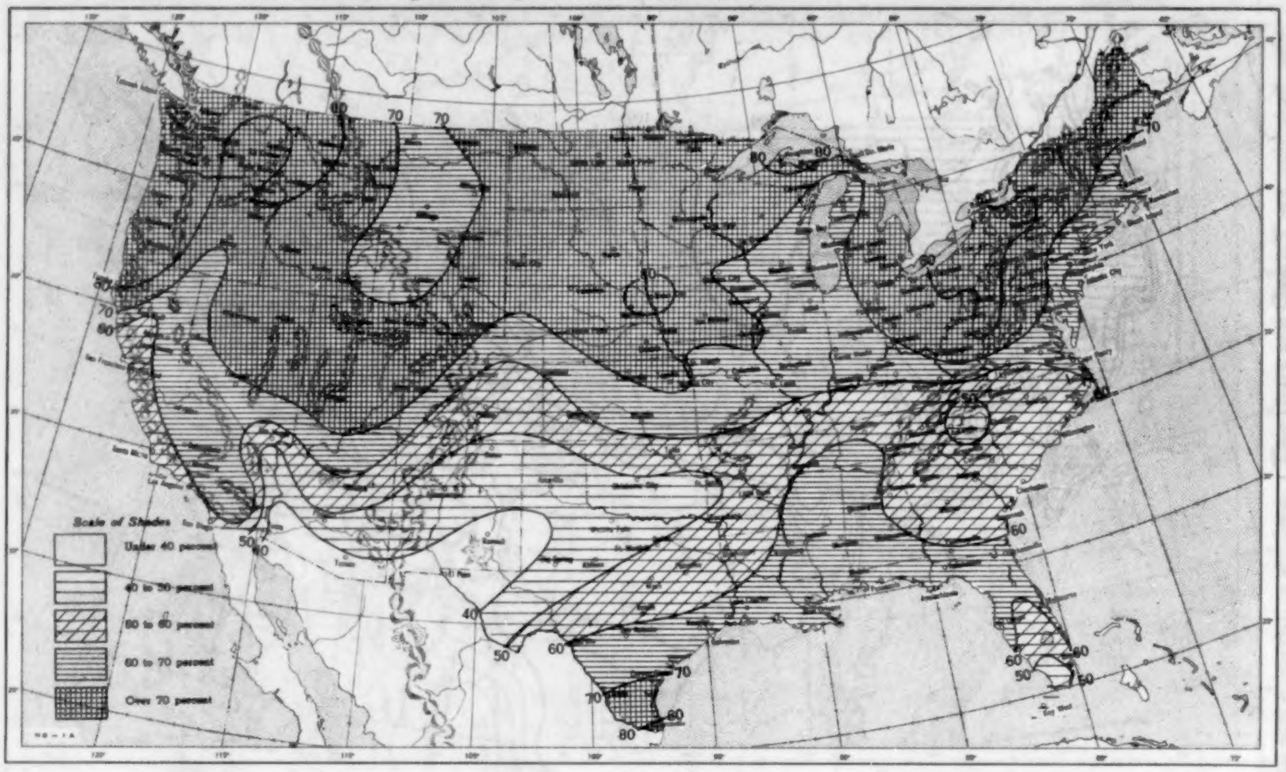


B. Depth of Snow on Ground (Inches), 7:30 a. m. E. S. T., April 1, 1952.



A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E.S.T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

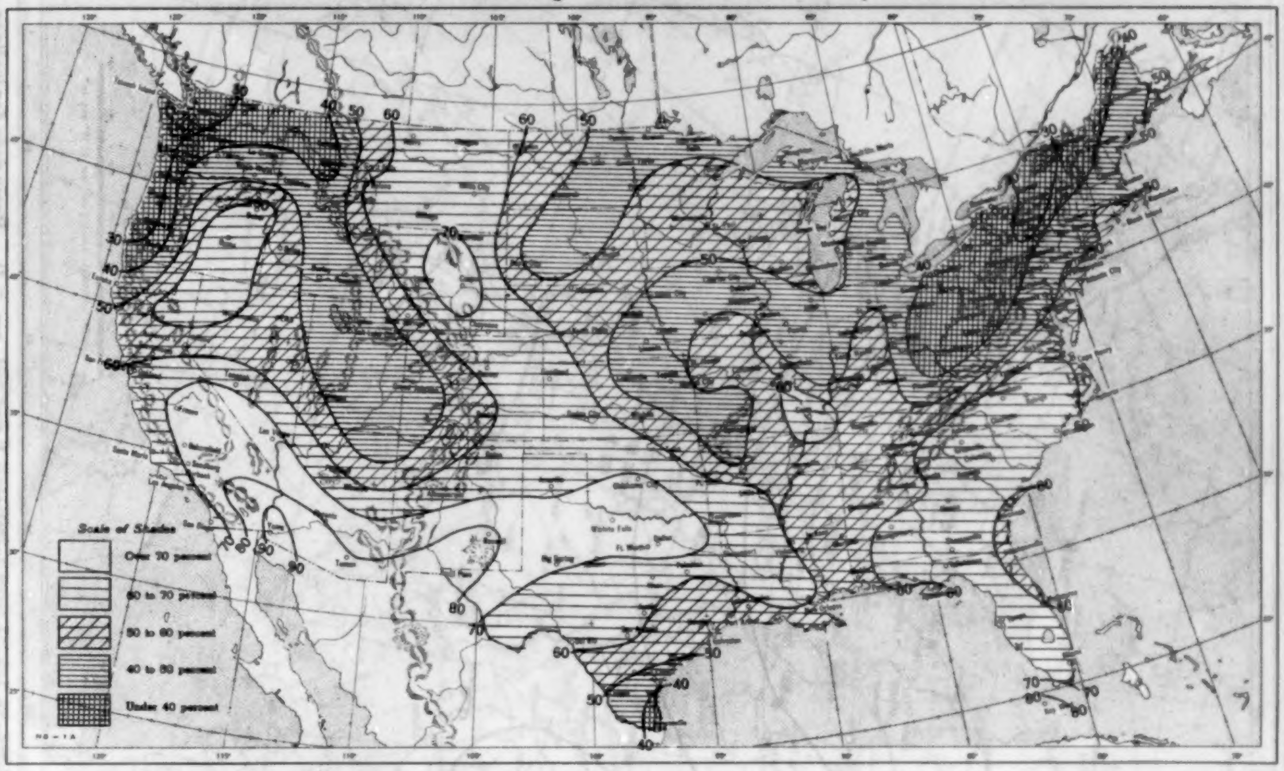
Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, March 1952.



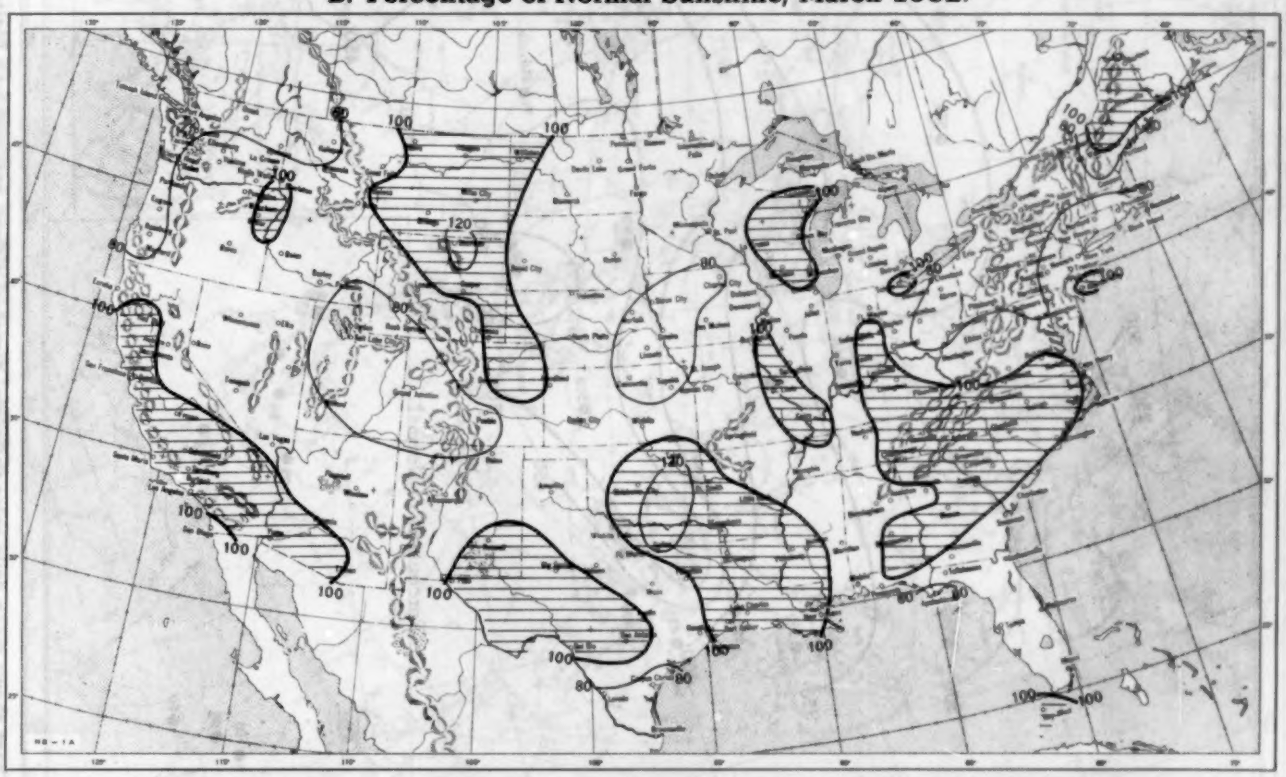
B. Percentage of Normal Sky Cover Between Sunrise and Sunset, March 1952.

A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, March 1952.



B. Percentage of Normal Sunshine, March 1952.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, March 1952. Inset: Percentage of Normal Average Daily Solar Radiation, March 1952.

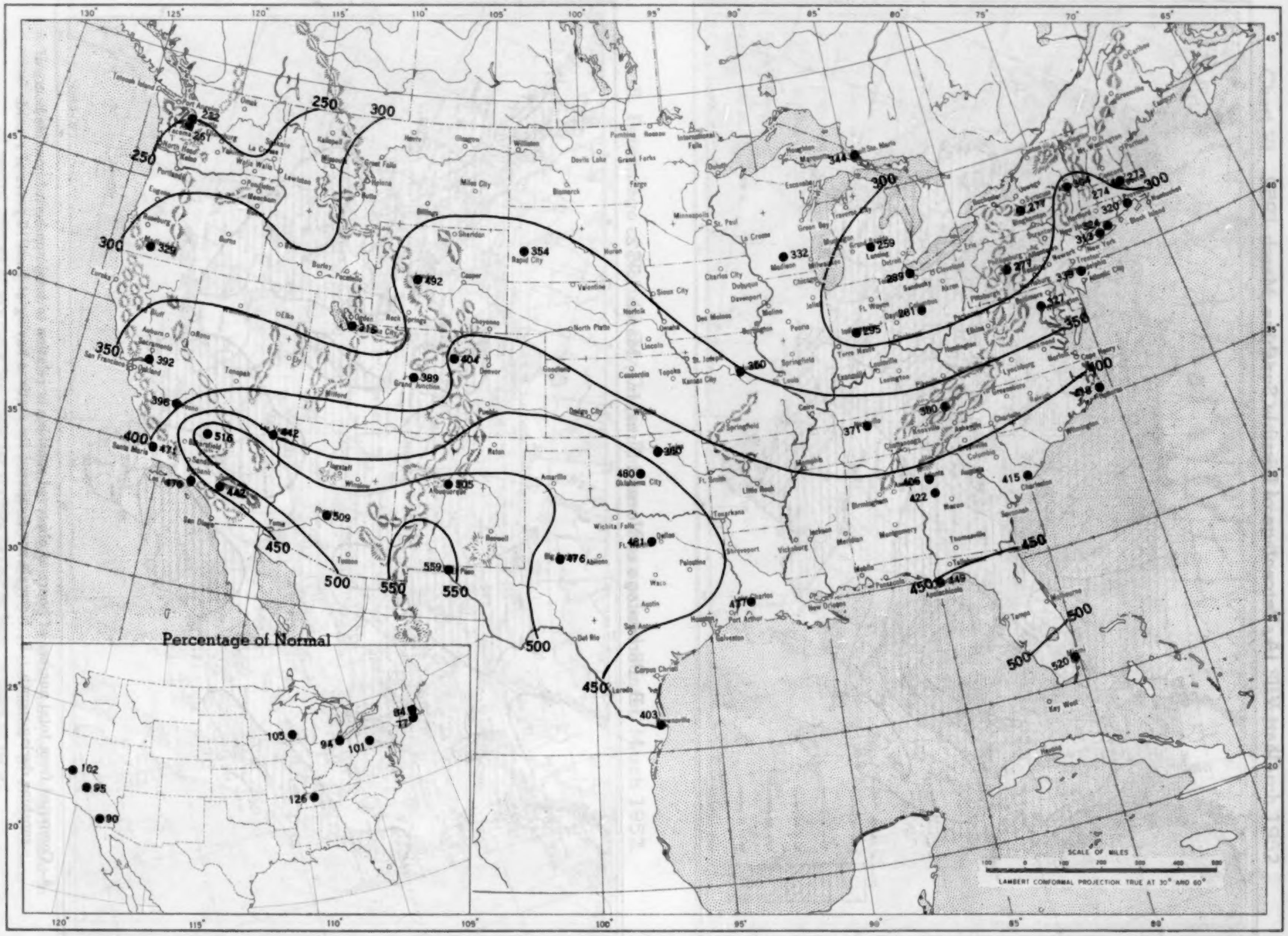
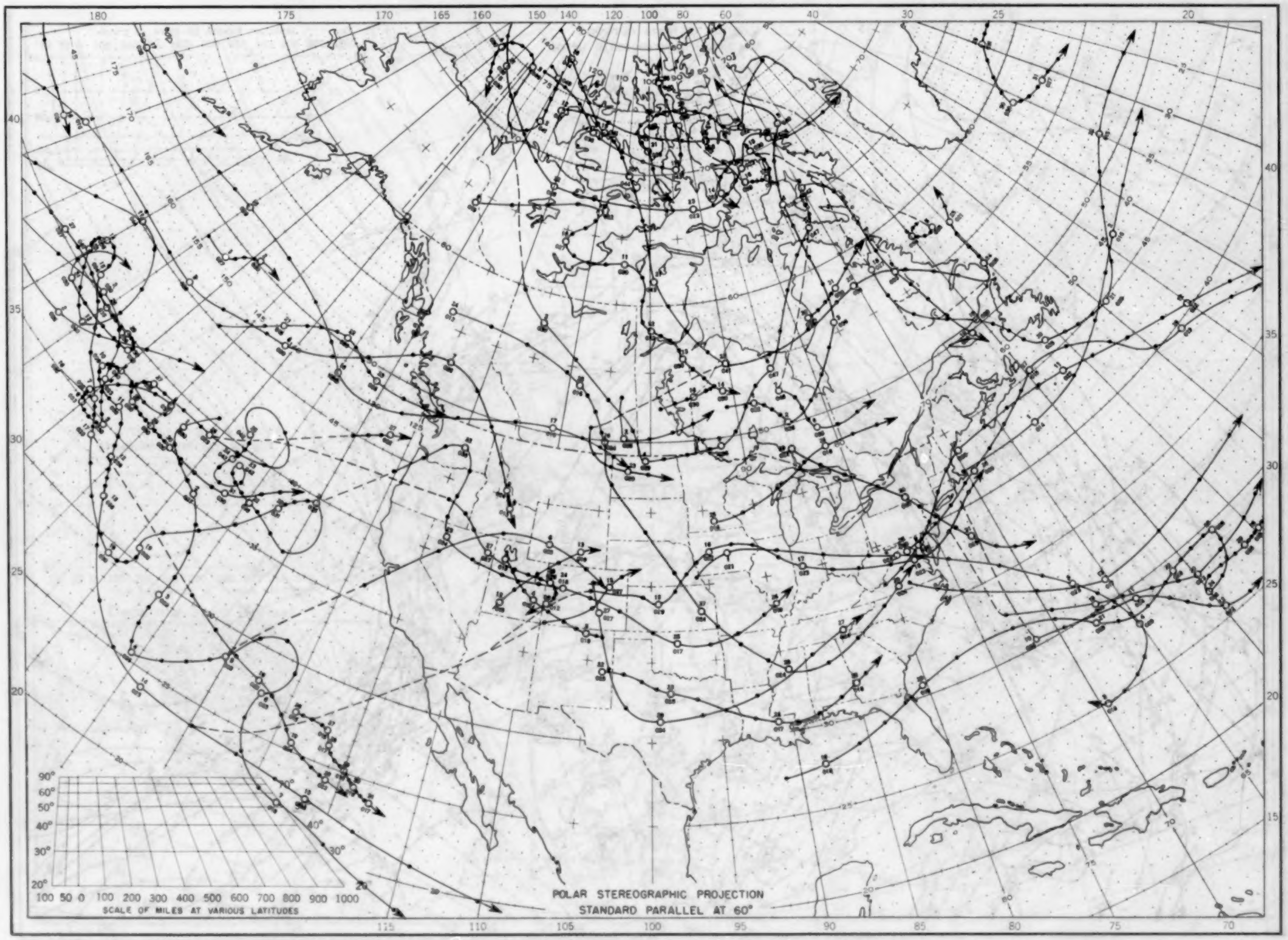


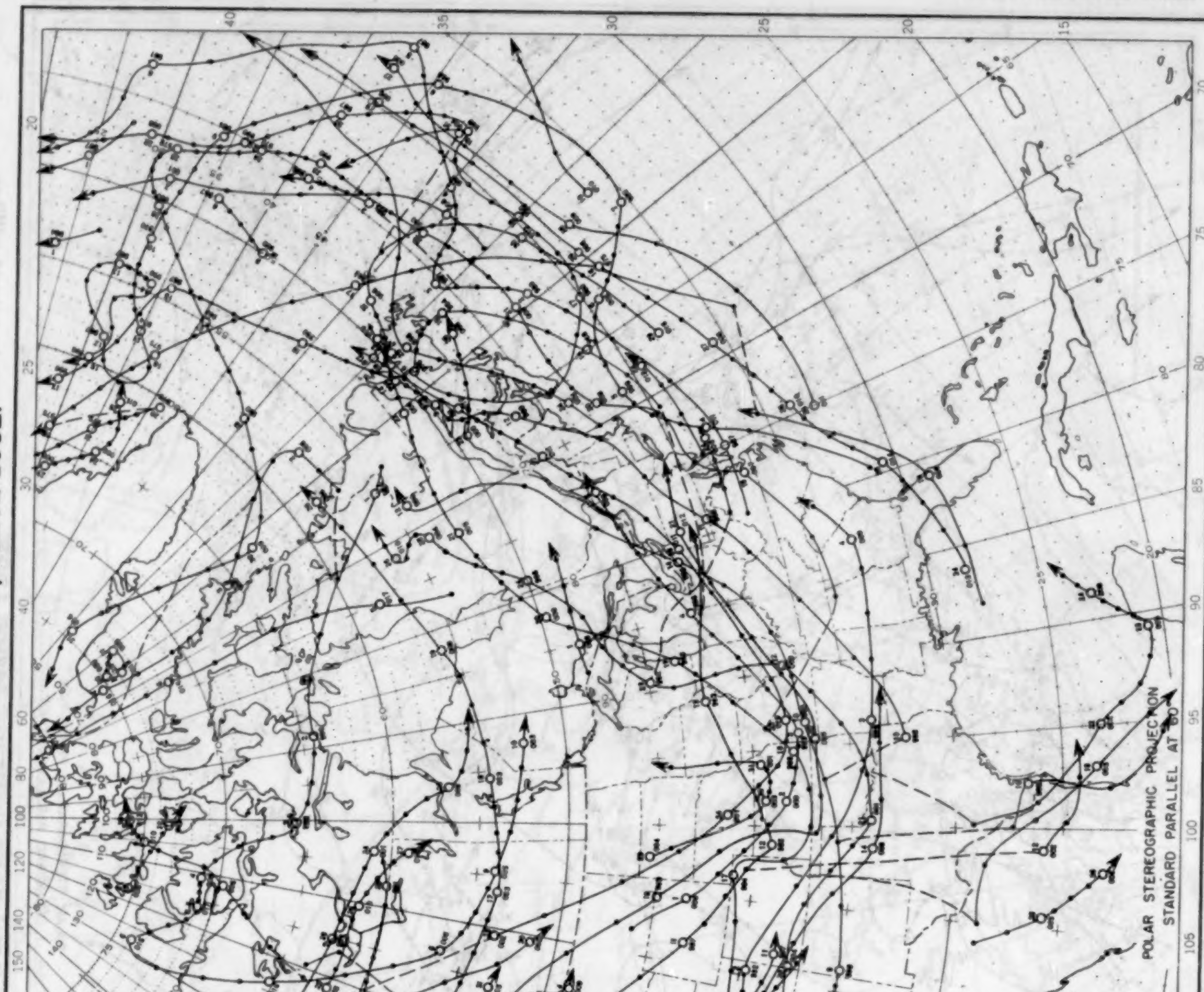
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, March 1952.



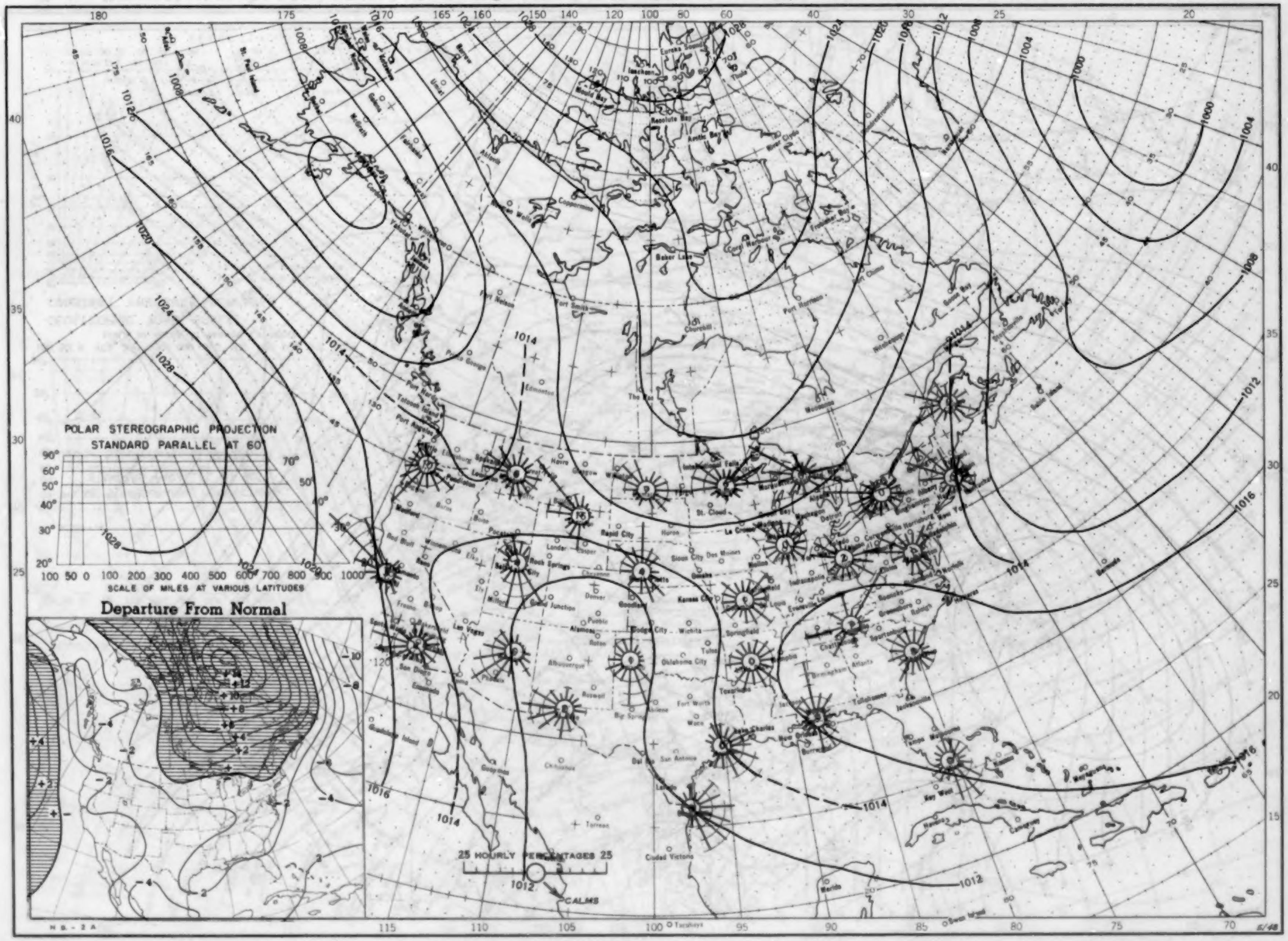
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, March 1952.



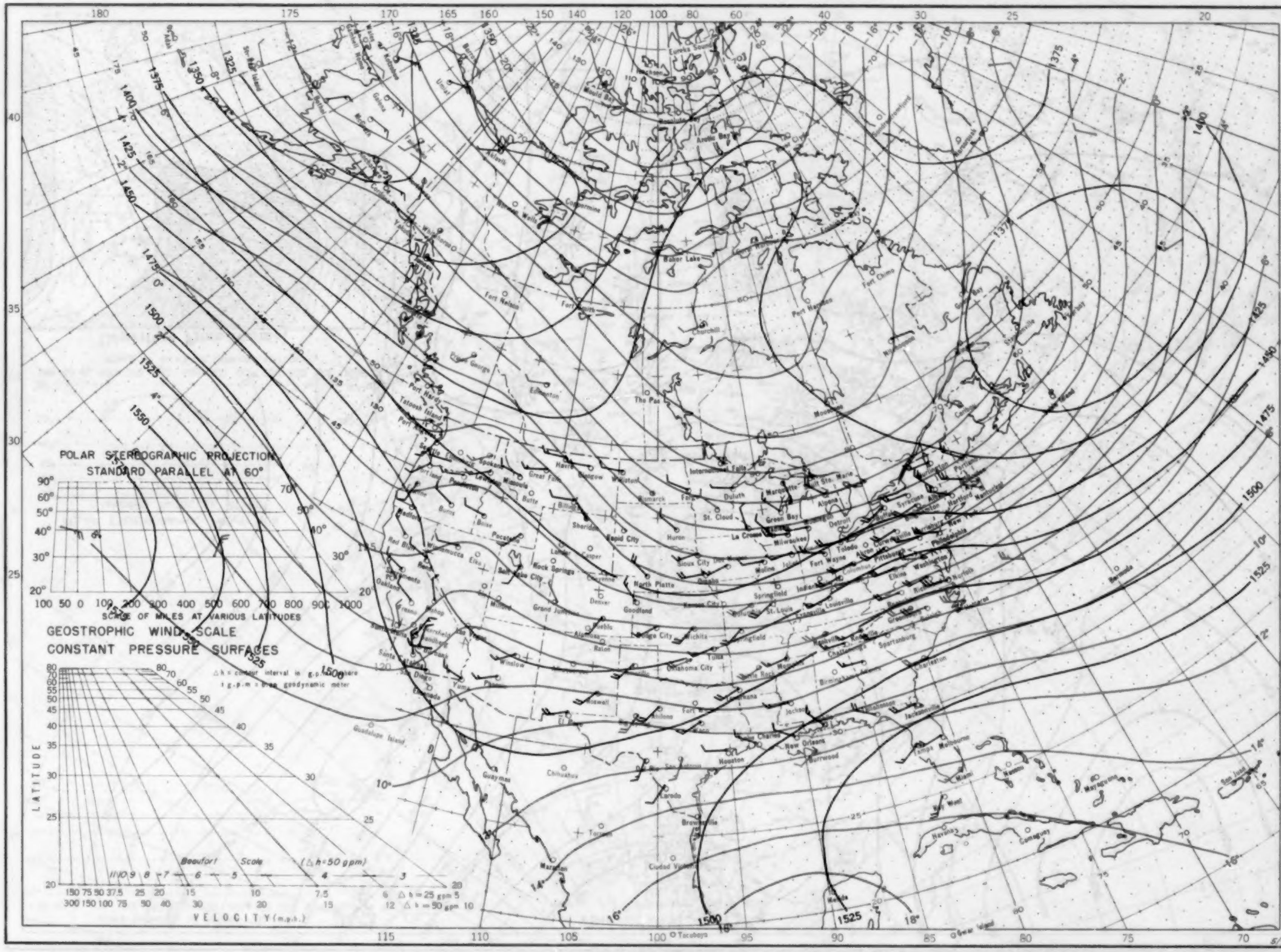
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, March 1952. Inset: Departure of Average Pressure (mb.) from Normal, March 1952.



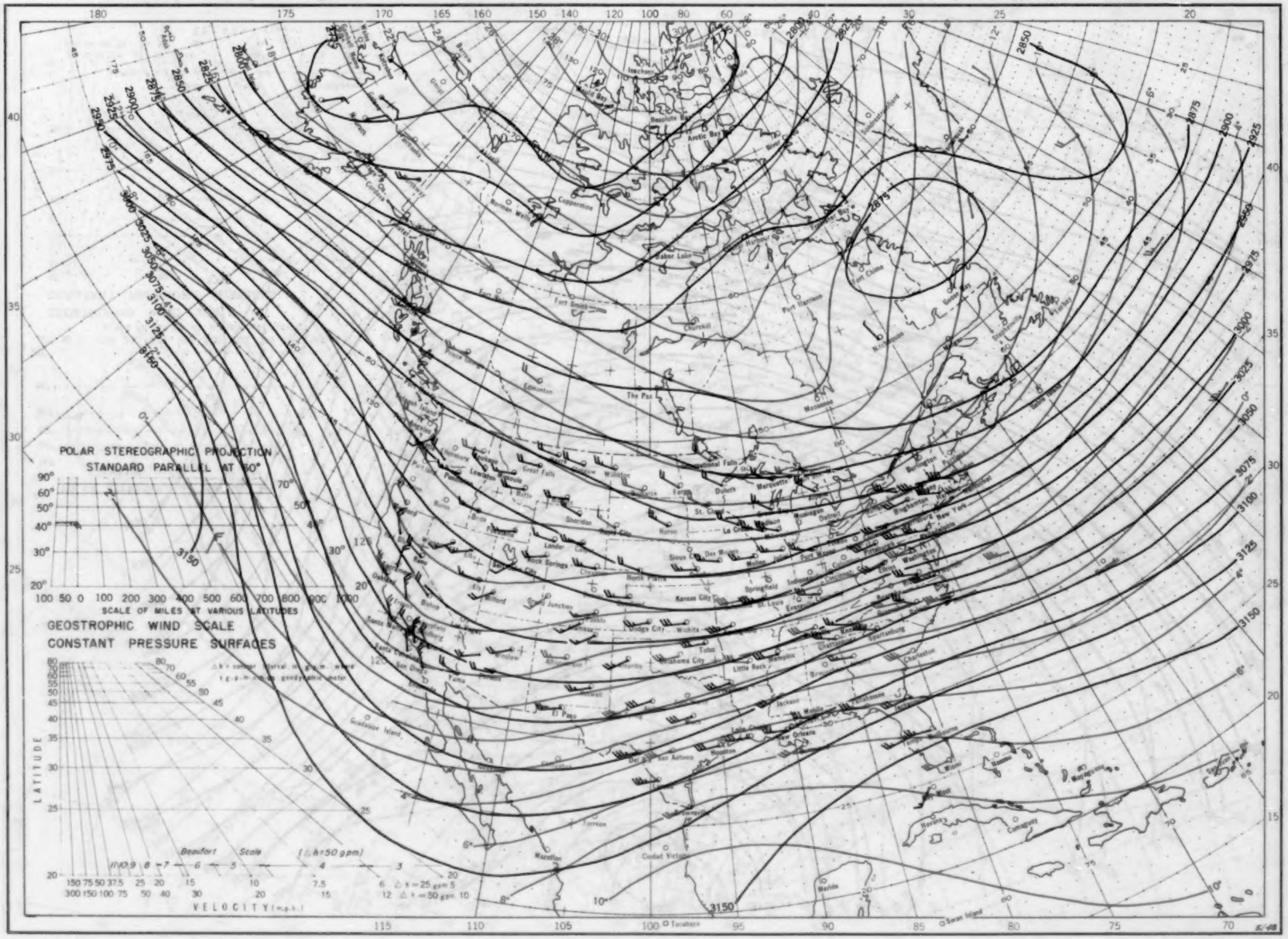
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), March 1952.



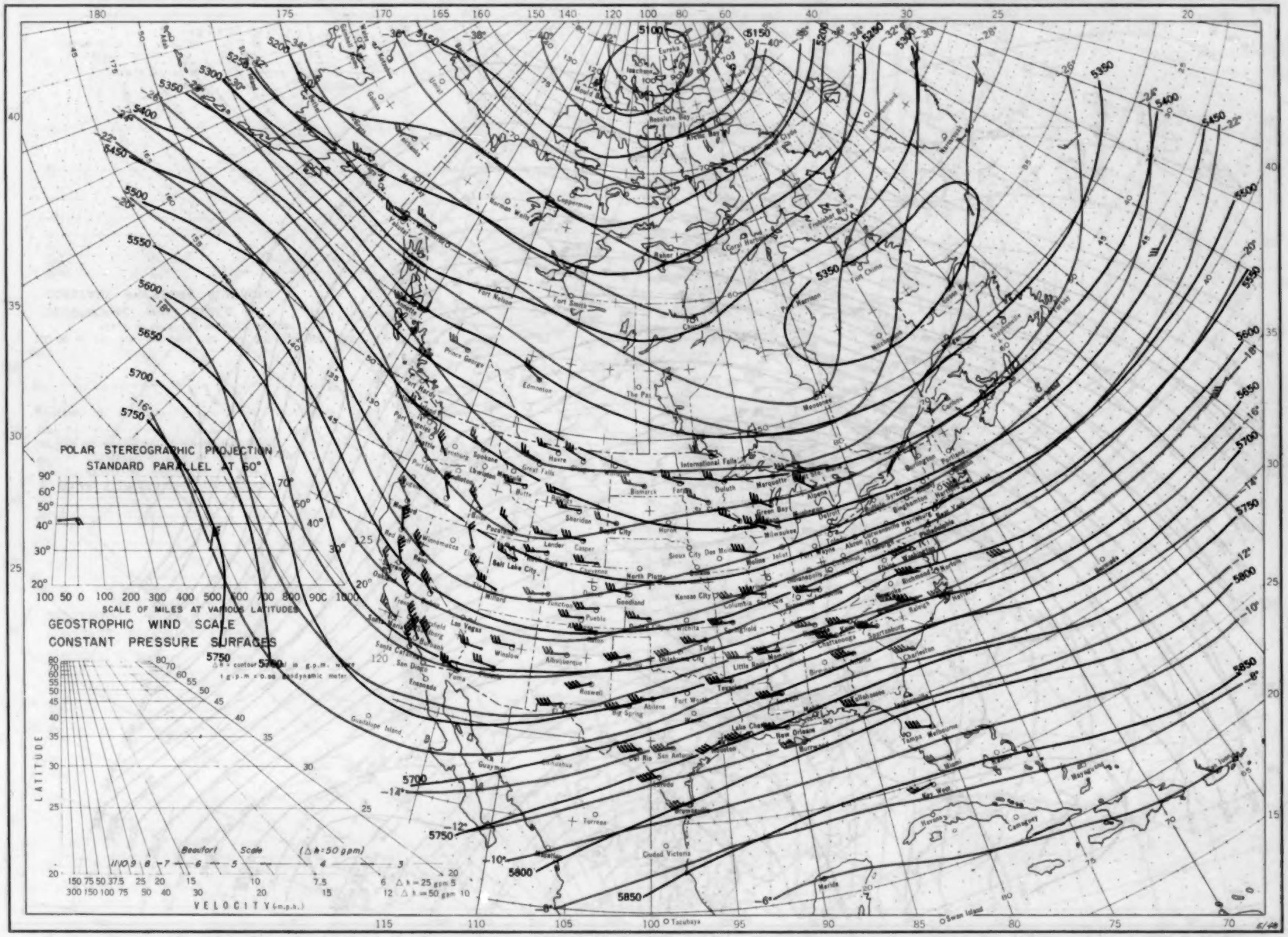
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), March 1952.



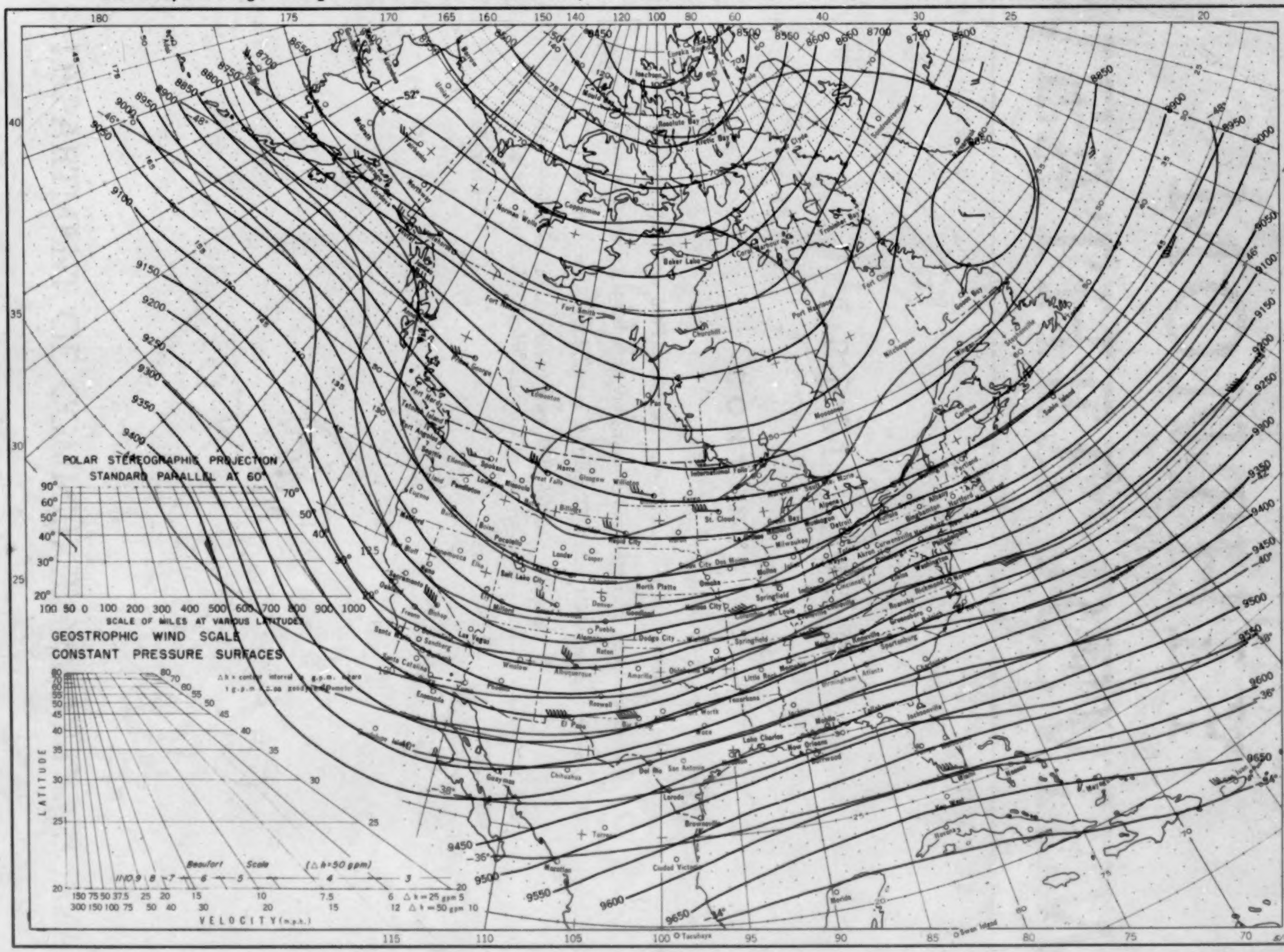
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), March 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), March 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.